

Cellular Building Components:

Investigation into Parametric Modeling and Production Logics

by Charles B. Austin

Bachelor of Arts in Architecture

The University of Texas at San Antonio 2001

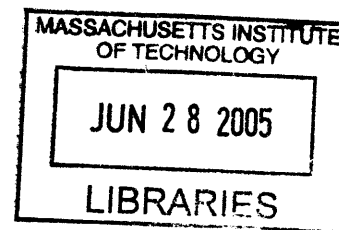
Submitted to the Department of Architecture

in Partial Fulfillment of the Requirements for the Degree of

Master of Architecture

at the Massachusetts Institute of Technology

June 2005



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1 / 1

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Cellular Building Components:

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by Charles B. Austin

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Recent advances in digital fabrication technologies have sparked a renewed interest in topology and biological form. The ability to design and prototype structural forms inspired by nature has challenged architects preconceived notions of space and form. With the assistance of parametric modeling and rapid prototyping we now not only have the ability to physically generate complex forms, but also the ability to create a seemingly infinite number of formal variations. As a result, this has caused architects to push toward new spatial concepts.

Among these new spatial concepts are those that seek to create entire building systems out of a single material solution. Inspiration for such systems can be found by studying organic cellular structures. Unlike the component based design processes of most architects, in which multiple problems are solved through multiple material solutions, natural systems tend to create solutions that solve multiple problems through one material solution. This thesis is interested in answering the question, "Is it possible to create a building system (both structure and enclosure) out of a single adaptable building unit?" Furthermore, can the building unit also be capable of transforming from being either permeable to impermeable? If so, how might this challenge our existing notions of boundaries?

Thesis Supervisor: J. Meejin Yoon
Title: Assistant Professor of Architecture

abstract

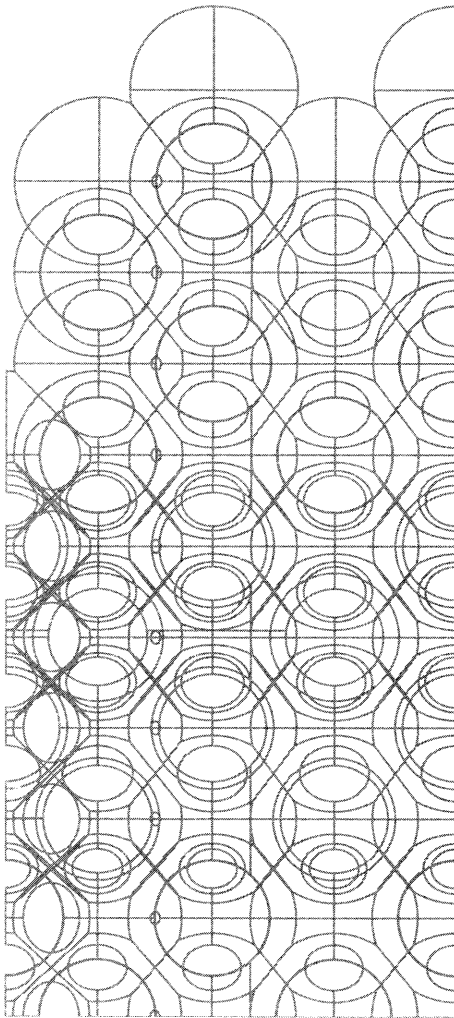
acknowledgements

I would like to dedicate this work to my parents, who have done everything in their power to provide this opportunity for me. I will be forever grateful.

Also, I would like to thank my brothers for the moral support they have given me.

To Katherine, thank you for being patient and standing by me throughout the obsessive pursuit of this Masters degree of Architecture. I hope I can be there for you the way you have been there for me during the tough times.

To my professors and peers, thank you for the dialogue we have maintained over the past several years. Our discussions and exchange of ideas have surely made an impact on the person I am today. I look forward to working with some of you in the future.



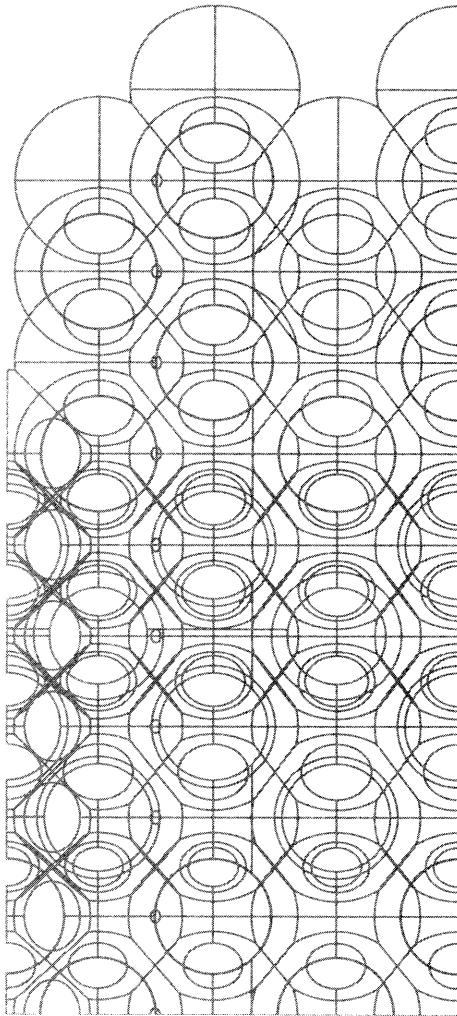
contents

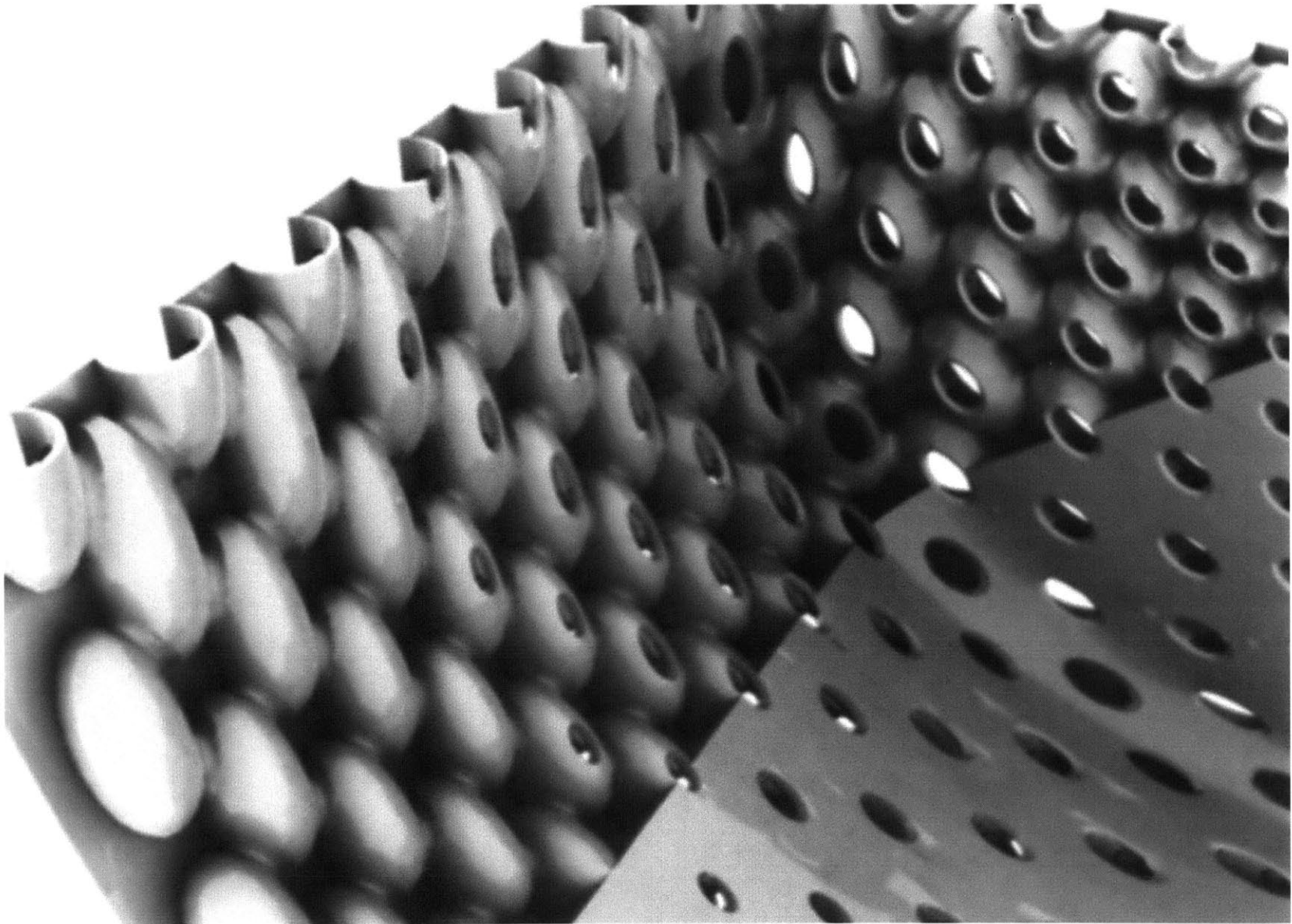
Introduction	6
Research	8
Production Logics	12
Parametric Logics	18
Configuration Studies	22
Aggregation Studies	60
Site	66
Intervention	68
• Conclusion	84
Bibliography	86

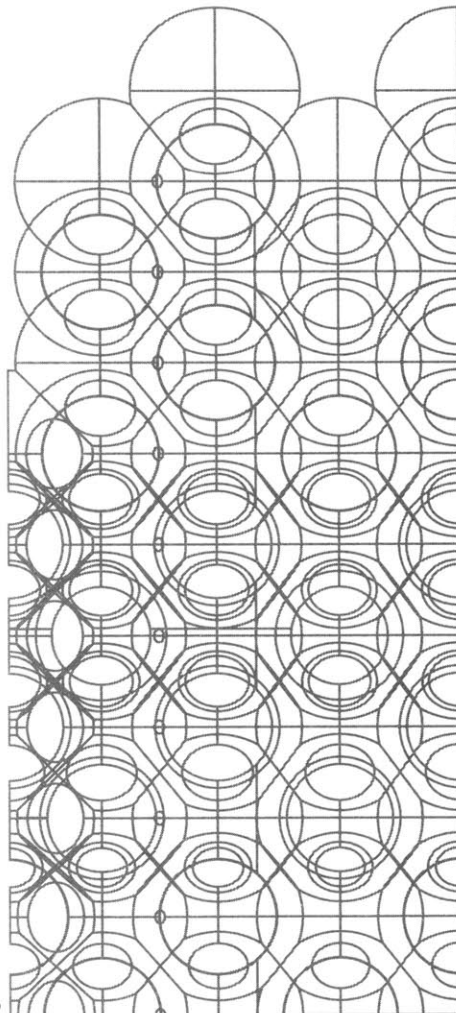
introduction

D'Arcy Thompson regarded material forms of living things as a diagram of forces that have acted on them. The motivations of this thesis will be to speculate how environmental criteria might affect material form. I seek to establish a set of operative relationships between multiple performance criteria, a variety of production strategies, and a particular material system such that each is parametrically linked to one another. The goal is to forge unexpected programmatic and formal combinations by fusing material and context.

This research will culminate in a series of prototypes that attempt to synthesize the entire process of creating a material system that is parametrically related to both performance criteria and production strategies.







Diatom - di•a•tom - Any of various microscopic one-celled or colonial algae of the class Bacillariophyceae, having cell walls of silica consisting of two interlocking symmetrical valves.

Or microscopically small unicellular algae with ornate silica shells

figure 1. IL 28: diatoms 1

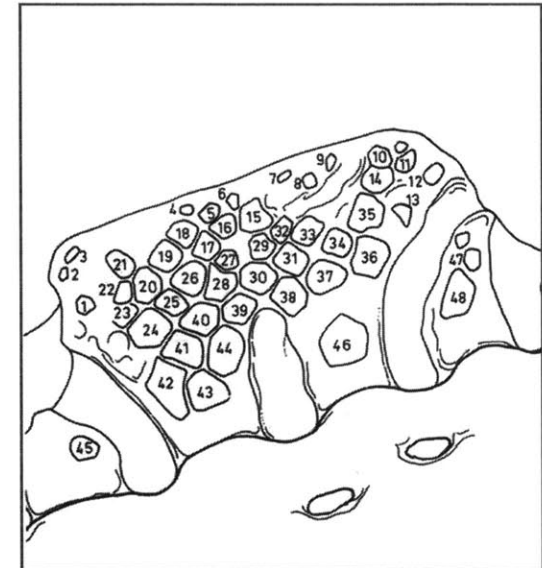
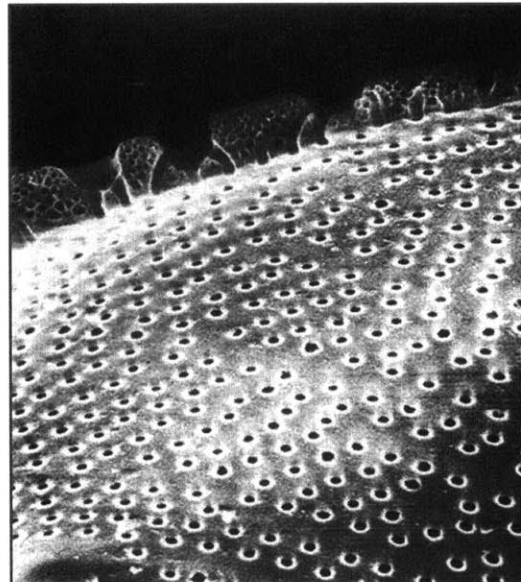
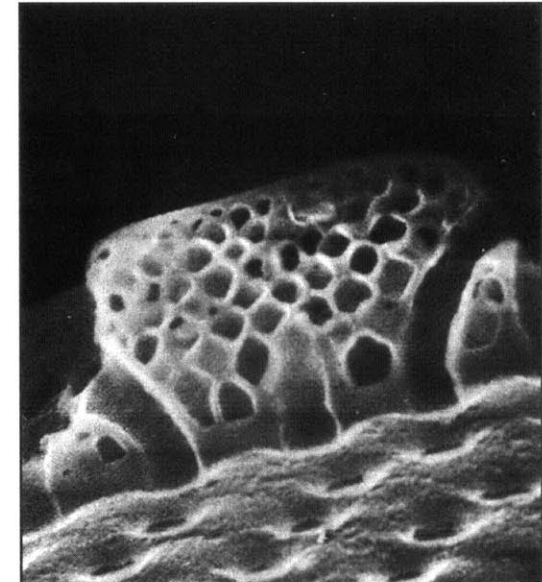


figure 2. IL 28: diatoms 1



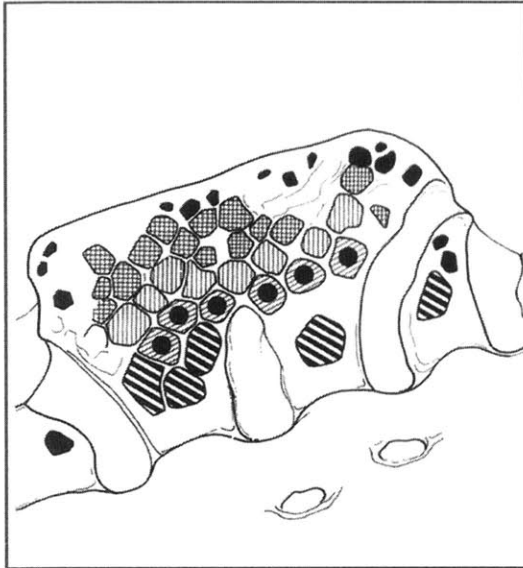


figure 3. IL 28: diatoms 1

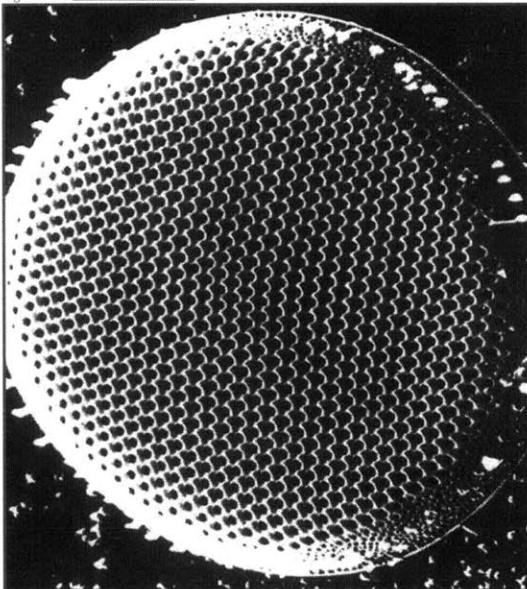
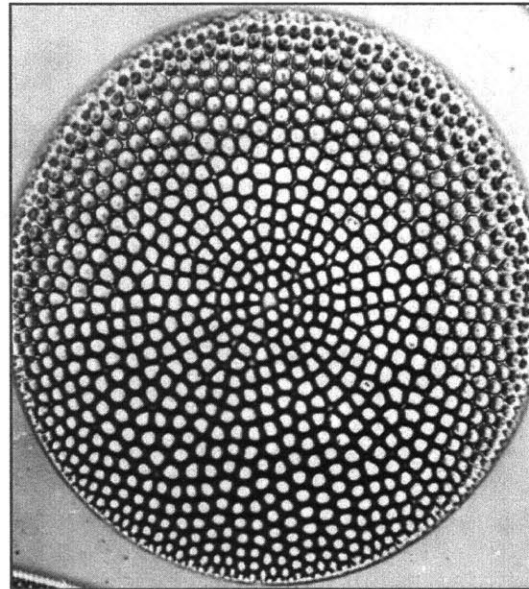


figure 4. IL 28: diatoms 1



Form as a Diagram for Forces

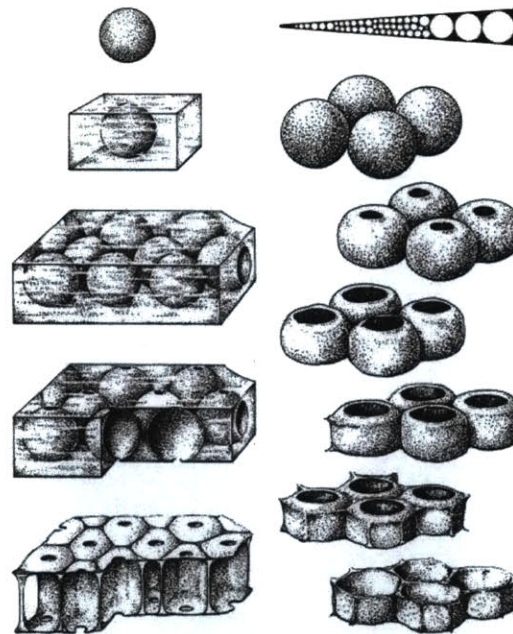
That nature creates forms and structures according to the requirements of minimum energy is perhaps the most pervasive theme throughout D'Arcy Thompson's book "On Growth and Form".

It is important to understand the resulting surface curvature in these examples to be the product of the section profile of the diatom. In this regard, it is possible to conceptualize the fabrication of the specialized space frame modules that, similar to the diatom, result in complex surface geometry.

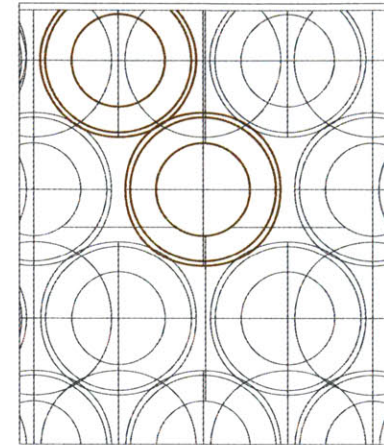
Minimum Inventory Systems

The principle of closest packing is equivalent to that of triangulation. Whether they are atoms, spheres, cells, linear, members, or surfaces. The components of a physical system have specific size, weight, and shape. The possible ways in which such components can fit together into alternating structures are governed by laws of symmetry. Since the cube has serious modular limitations, I have opted to develop a spherical unit. Small transformations to each individual unit create a large transformation of form.

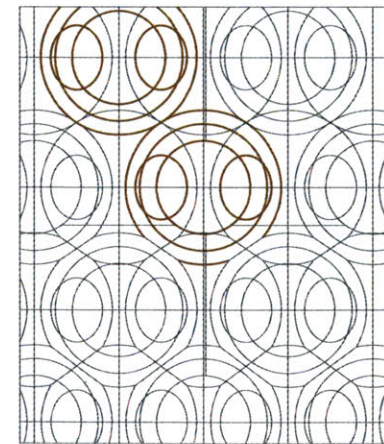
figure 5. IL 28: diatoms 1



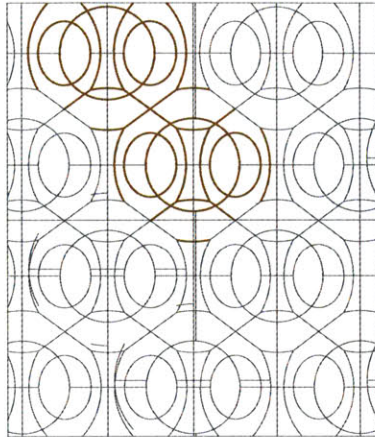
Pattern A



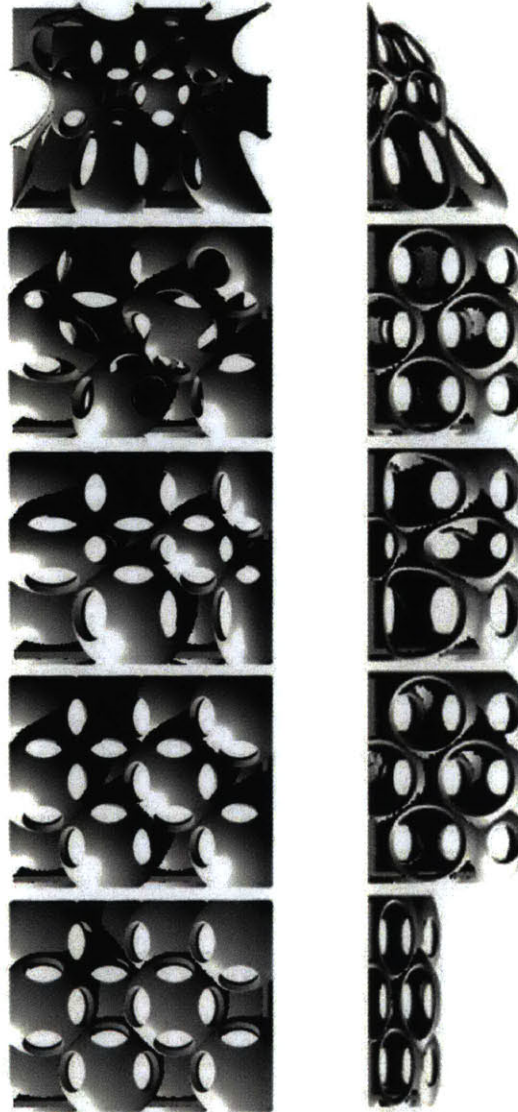
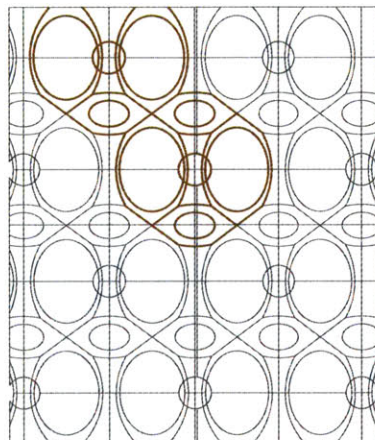
Pattern B



Pattern C



Pattern D



Through careful examination of these diagrams, you begin to realize that the network of cells begin to form a type of space frame. The significance of space frames is that they offer the potential to articulate structural response in the depth of the surface. The magnification of the fibrous cellular structure of bone tissue demonstrates nature's intelligence in the proliferation of repetitive members that manage to differential loading conditions through their randomness and redundancy.

A major goal of this project will be to design an intelligent building component that has similar characteristics to the bone tissue described above. In other words, the component must have embedded within it, the intelligence to react to its loading, network and local conditions.

production logic

Composite Assemblies

"Materials are no longer finishes that provide closure to a building. Instead they are crucial starting points that open new possibilities for structuring the experience of space, for rethinking the seemingly banal surfaces of partition, curtain wall, chase space and hung ceiling that characterize the familiar landscape of contemporary building types."

-Sheila Kennedy, "Material Misuse"

I think it is through a process such as this—developing an all in one building system—which one can begin to interrogate what a wall wants to be now that we are able to embed emergent technologies at various different scales. If the building system is porous even at the microscopic scale of the material, then you can begin to imagine embedding infrastructure at various different scales.

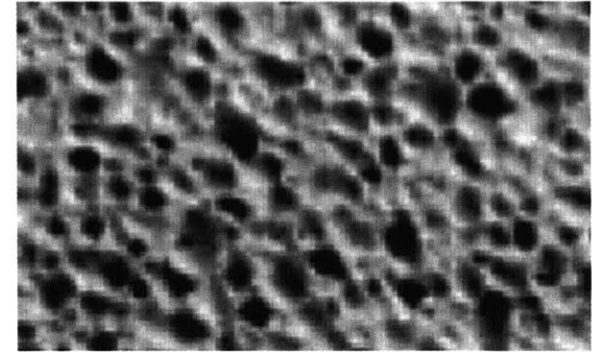
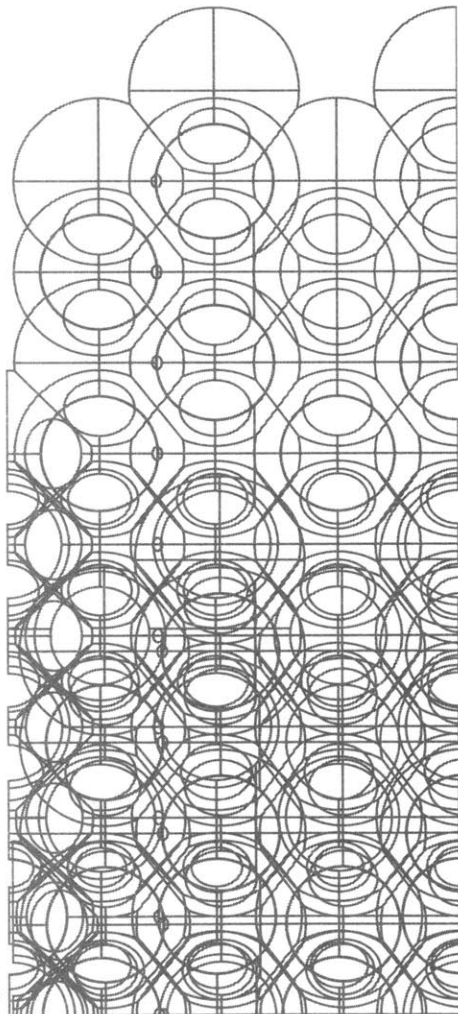


figure 6. Material Misuse

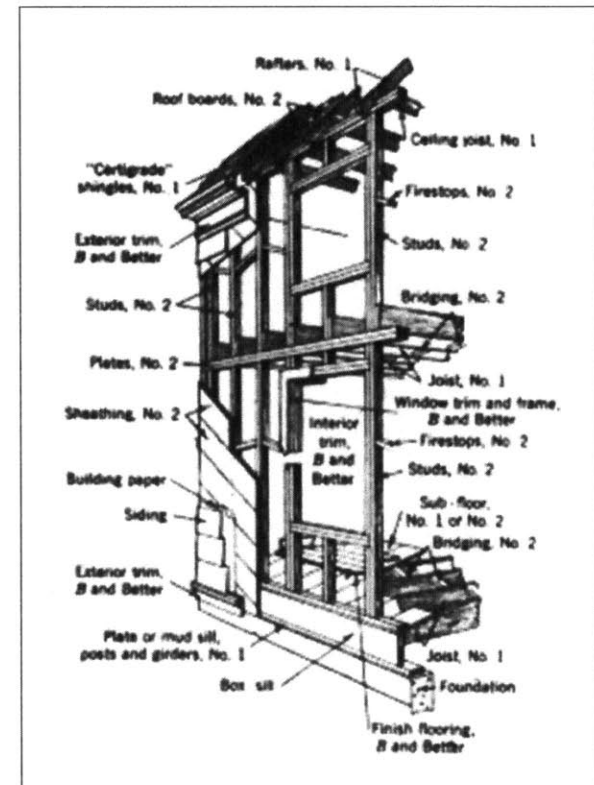
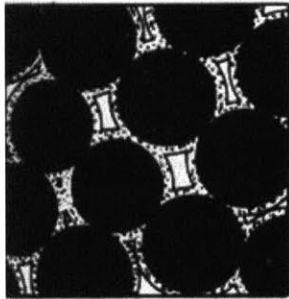
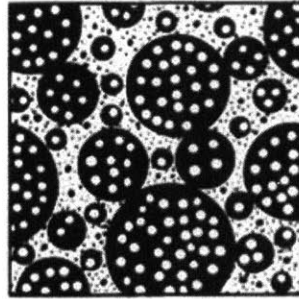


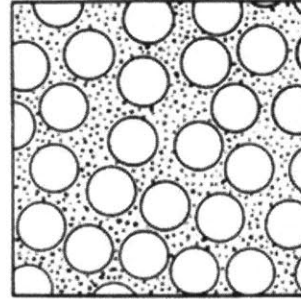
figure 7. Lightweight Concrete



1. no - fines

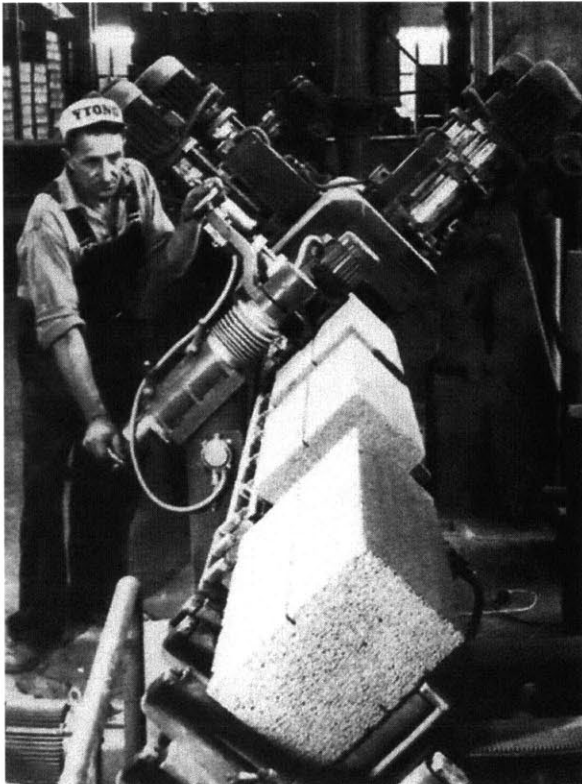


2. lightweight aggregate



3. aerated

The three basic types of lightweight concrete



Aerated Concrete Mixture

The gas formation may be illustrated in the following equation which has been simplified for clarity. Other aluminates may also be formed.

Aluminum Powder
Hydrated Lime
Tricalcium aluminate hydrate
Hydrogen



Powdered zinc may be used instead of aluminum, in which case calcium zincate and hydrogen are formed. In either case the hydrogen produced in the cells is quickly replaced by air.

Another aim of this project is to develop a component that is relatively easy to fabricate and construct.

precedent 1

Millard House: Textile Block House

- Frank Lloyd Wright, Wright in Hollywood

Frank Lloyd Wrights Textile block design is an ideal precedent primarily because the blocks are relatively easy to fabricate and construct.

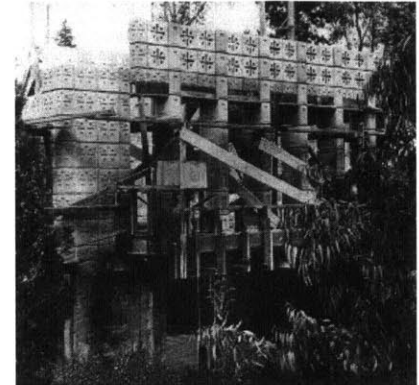


figure 6. Wright in Hollywood

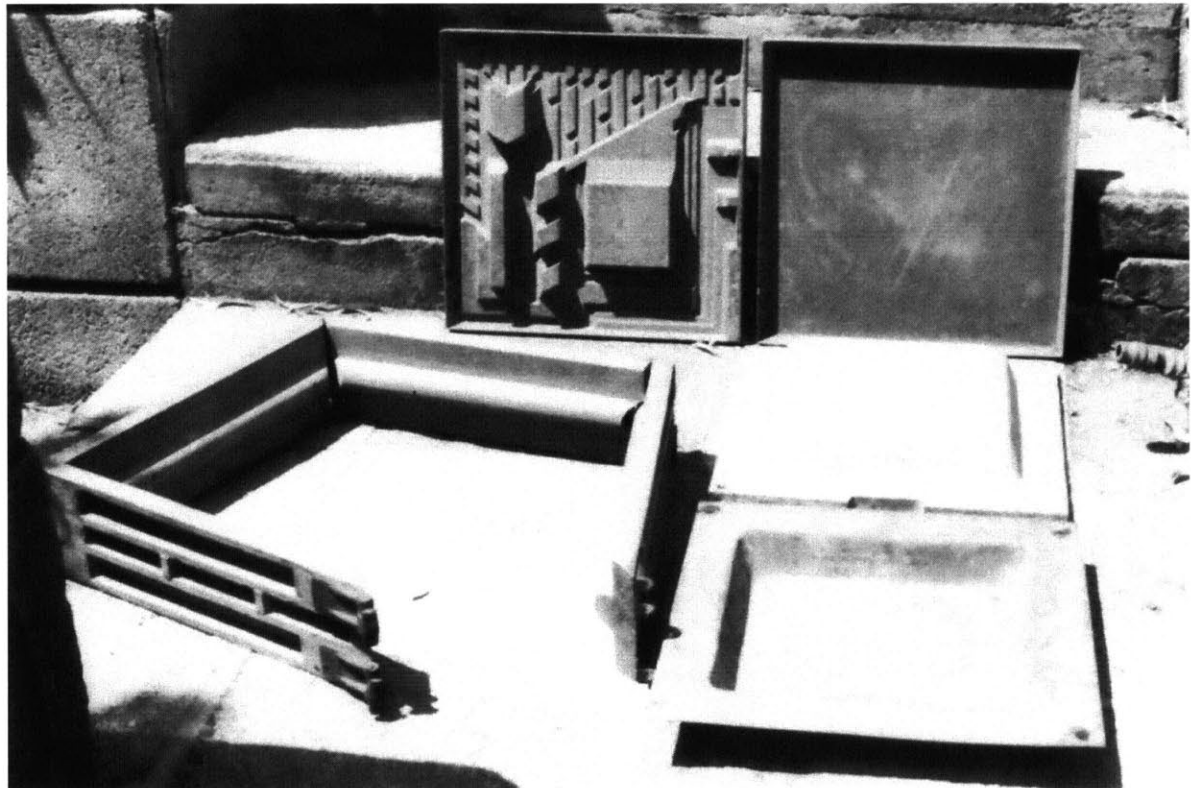
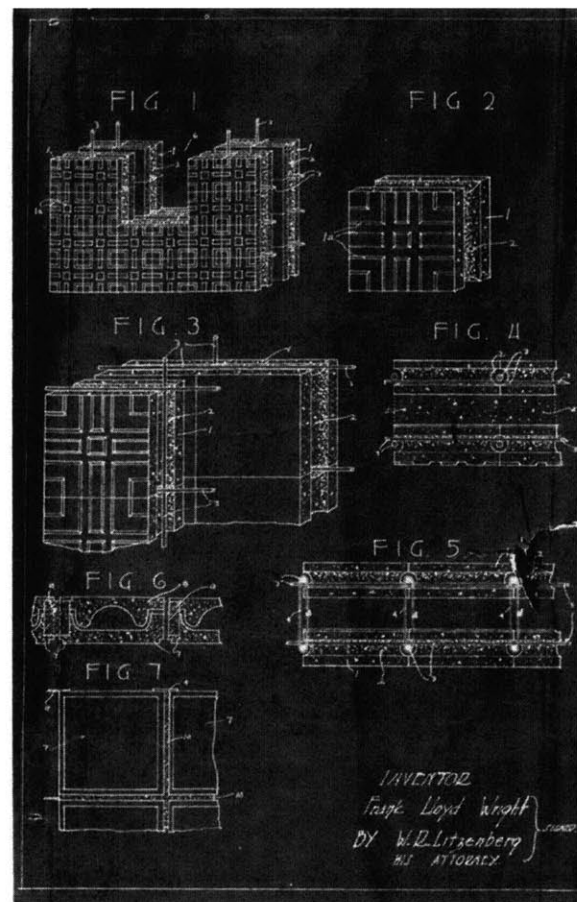
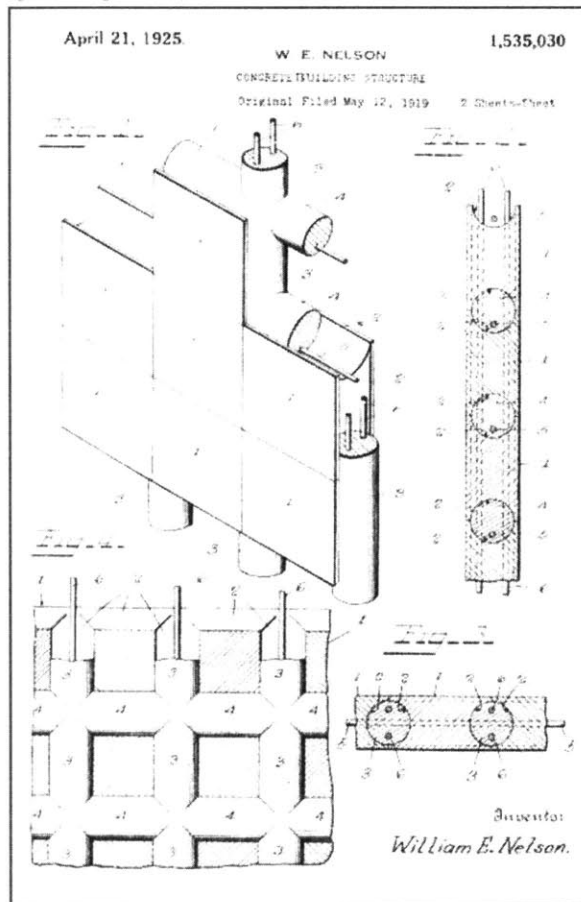


figure 9. Wright in Hollywood



Textile block assembly details

These assembly drawings illustrate the simplicity of the system. The blocks are held together by a grided wire mesh.

precent 2

Continua

"Continuity and potential infinity have been at the very center of my sculpture from early on. I derived the notion of a continuous surface primarily from my studies of biomorphic form."

- Erwin Hauer, *Continua*

Hauer's modular system aggregates at roughly the same scale as Frank Lloyd Wright's system. However, unlike Wright's Textile Block, Hauer's modular component has the ability to filter and diffuse light and sound.

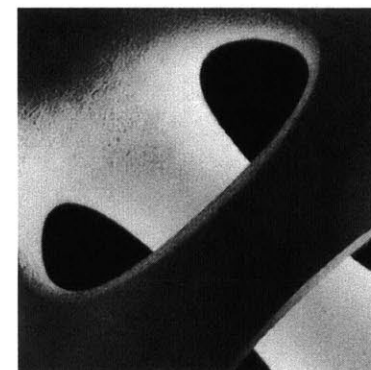
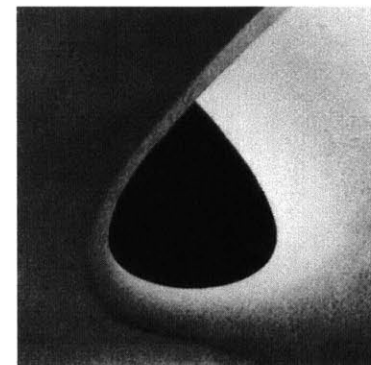
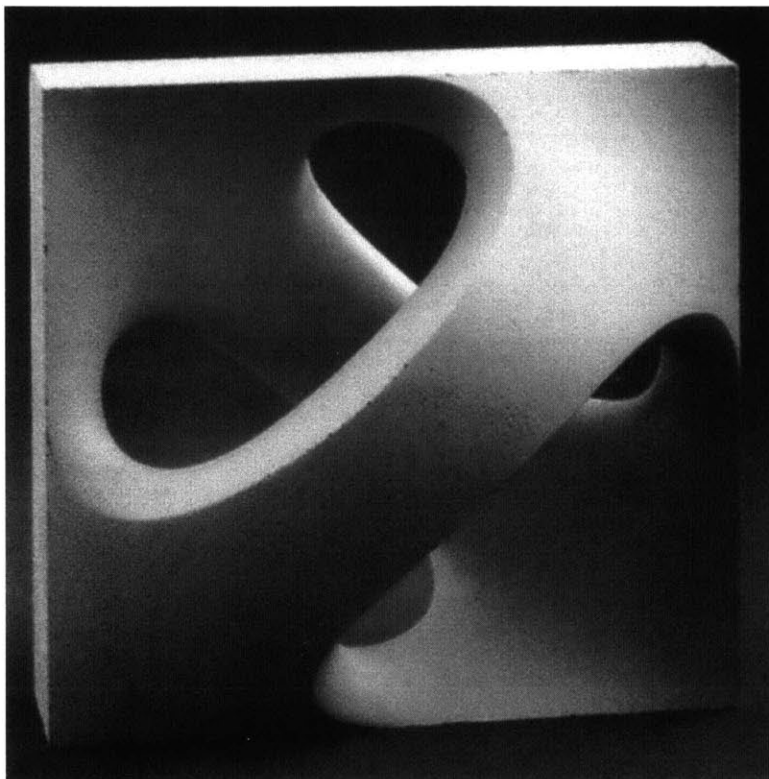
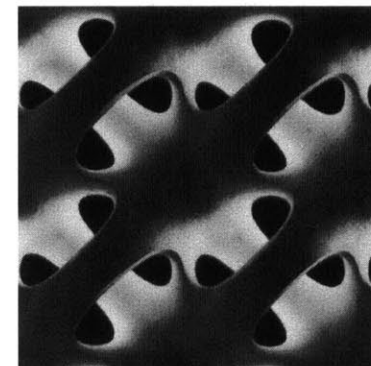
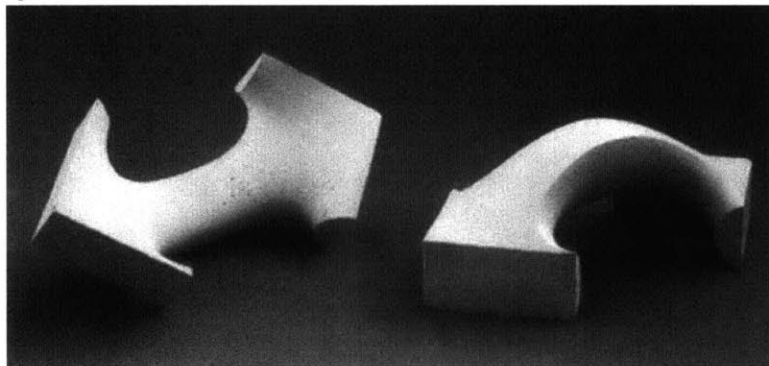
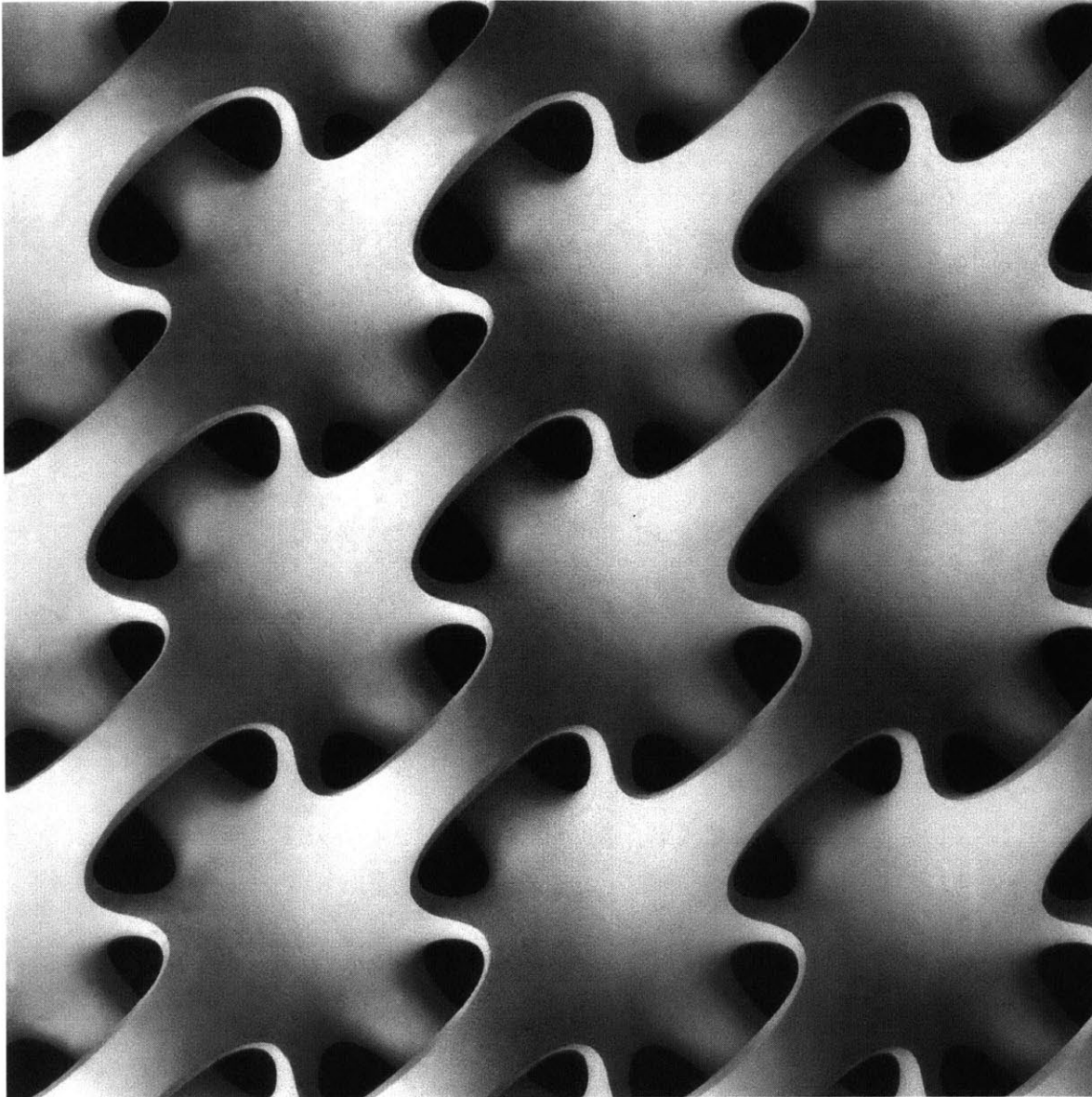


figure 10. *Continua*

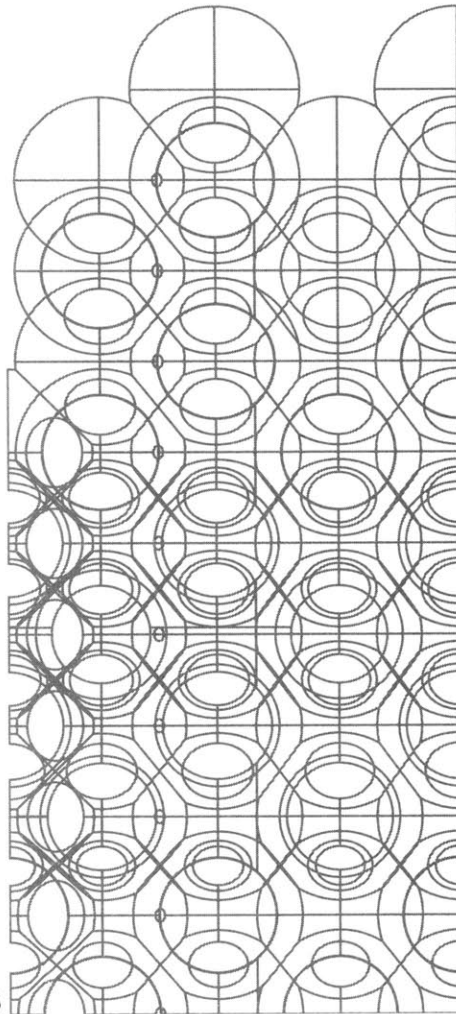




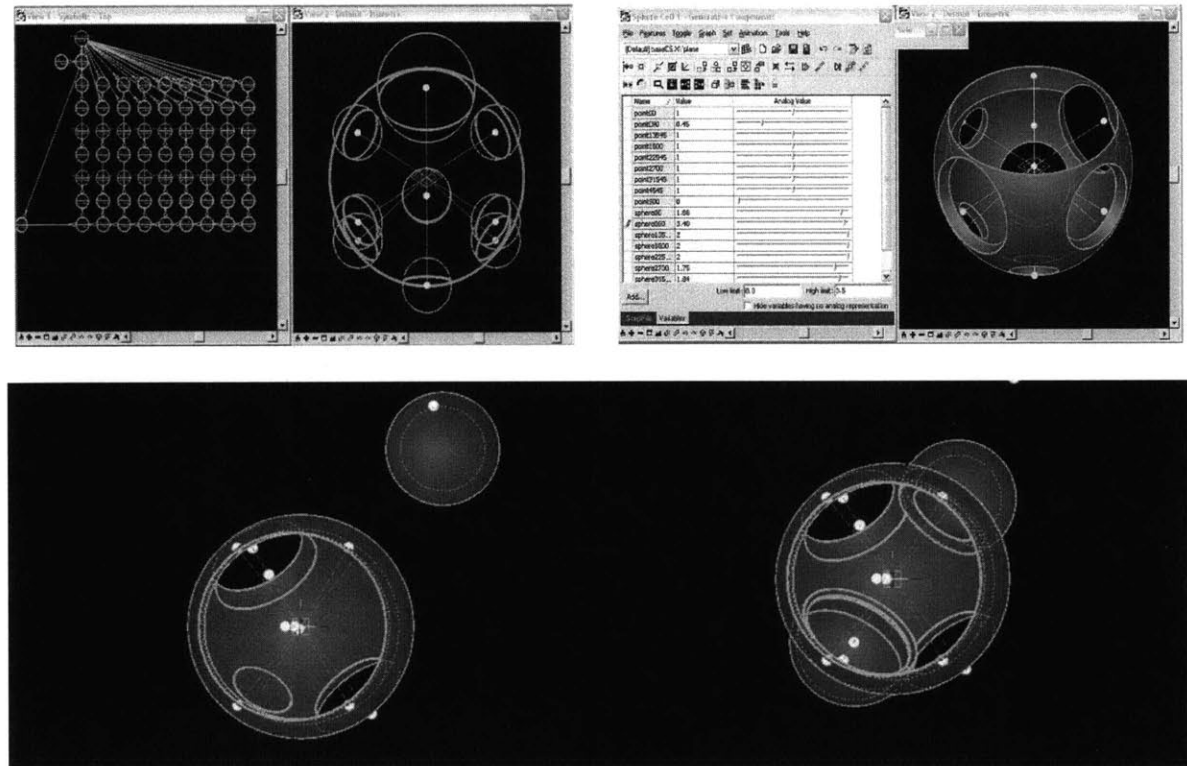
design 1, 1950

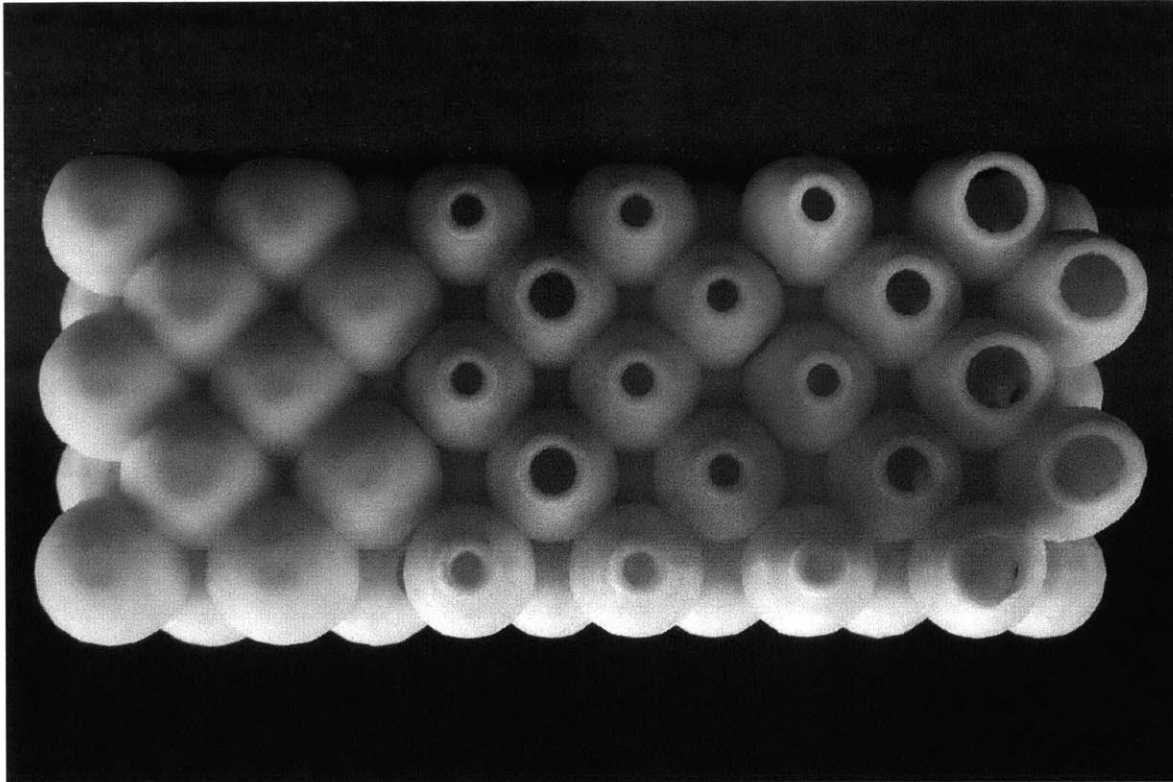
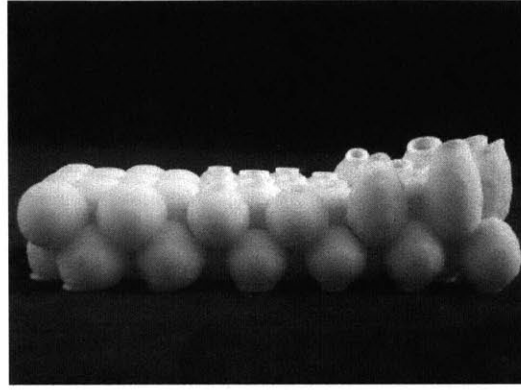
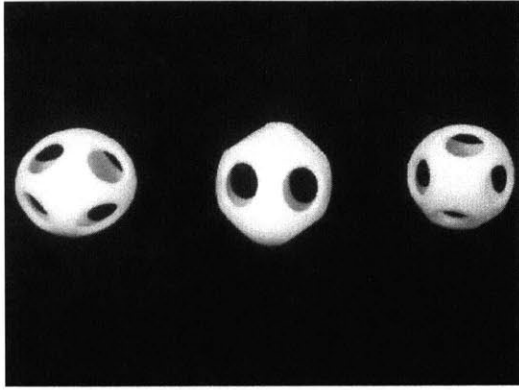
By aggregating the three-dimensional modules in a field, Haur was able to create a continuous surface that had a spatial depth. Although his designs were visually beautiful, they were mostly served no function other than screen walls. Also, the wall systems were completely homogenous, therefore they could never escape uniformity. Despite these shortcomings, they serve as a good starting point for this investigation. By parameterizing the sectional members of each component, one can begin to imagine slight variation throughout the surface of the wall. By allowing for such slight variations to occur, one could also imagine that the system is able to react to its surroundings by becoming more or less permeable.

18



The goal is to utilize Generative Components to span the architectural process from concept formation to digital fabrication in a system of related models.





Cellular network transformation

A large part of the design of the cellular component is that it has the ability to respond to information from its surroundings. This image illustrates how the network of cells can go from being completely impermeable to permeable. The image also demonstrates how the system is parameterized to thicken if necessary.

Parametric behavior

It is the power of the computer to simulate and iteratively reconfigure through parametric control that brings in increasingly innovative means by which digital space and analog space start to inform each other and produce a resulting new tectonic. It is my goal to move from digital models to physical constructions through interpretation, translation, and fabrication.

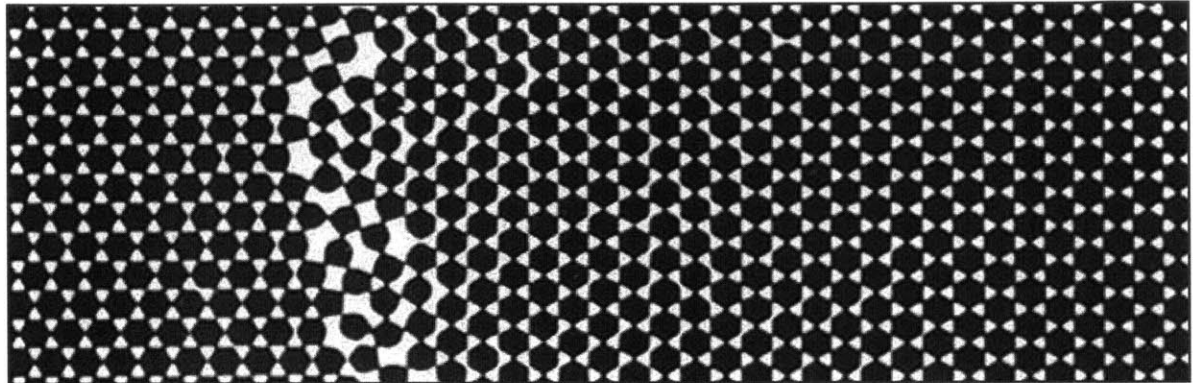


figure 11. IL 28 Diatoms

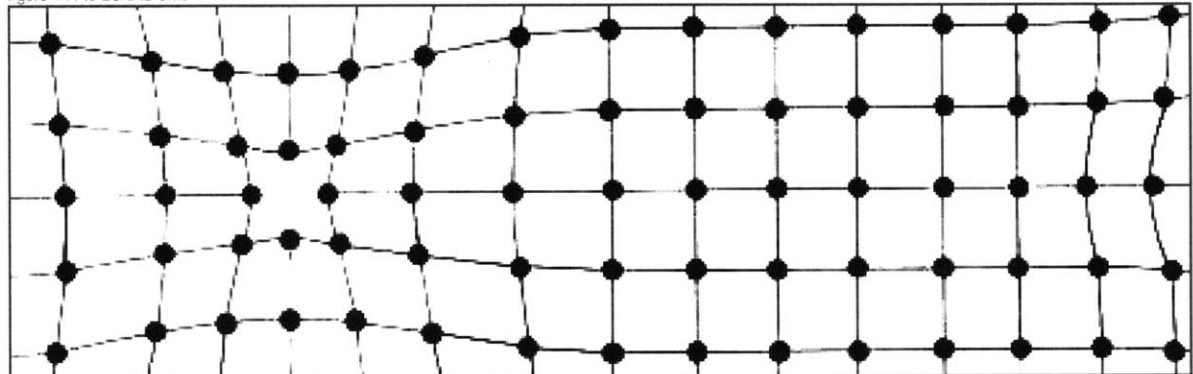
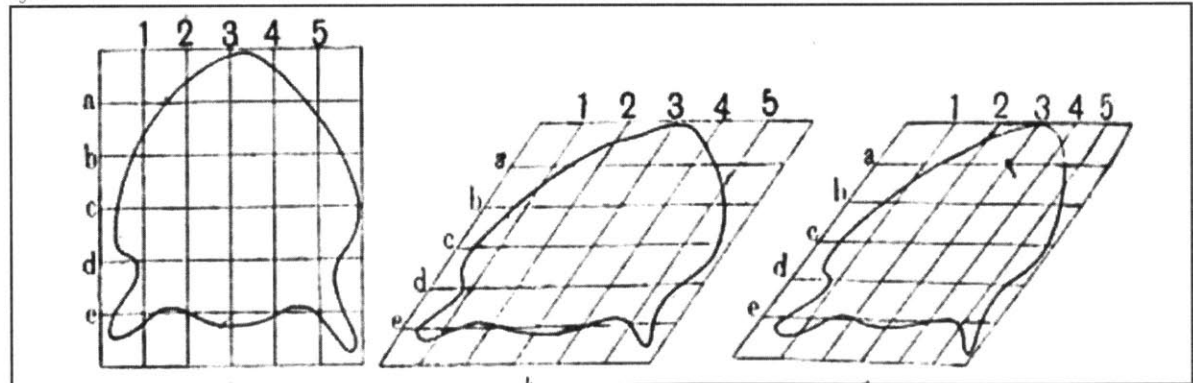
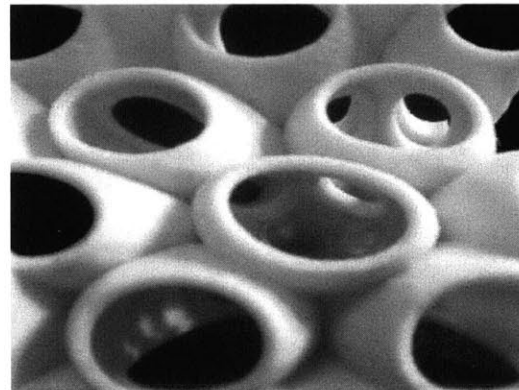
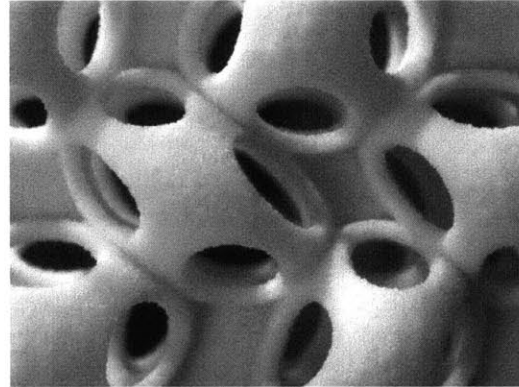
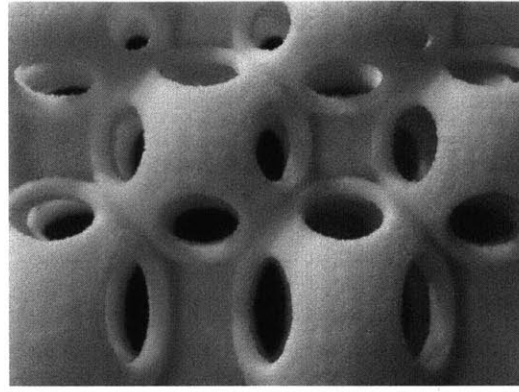
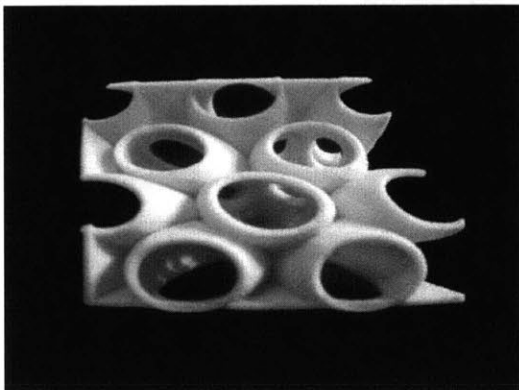
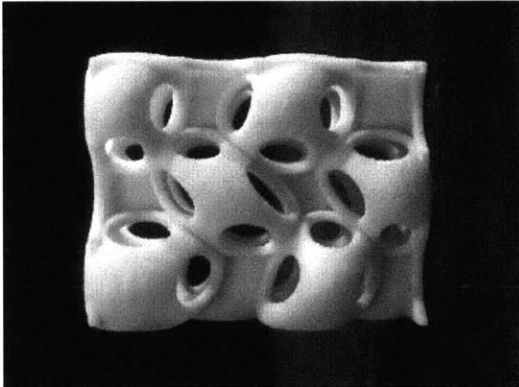
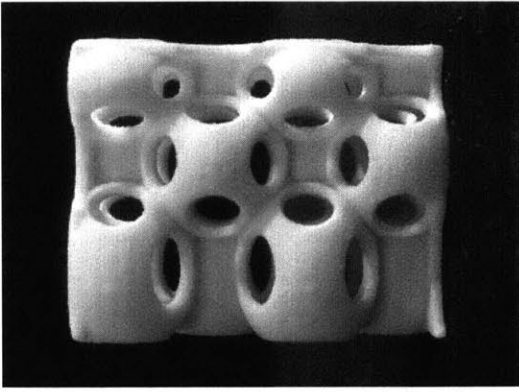


figure 12. On Growth and Form

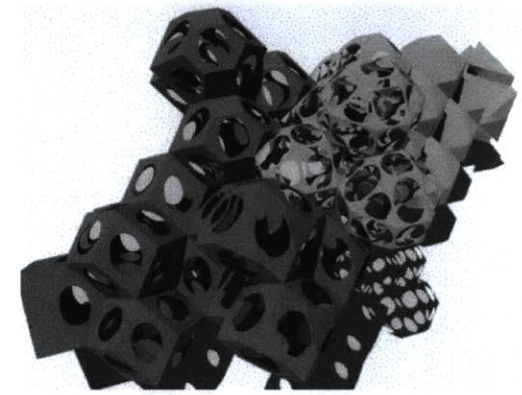
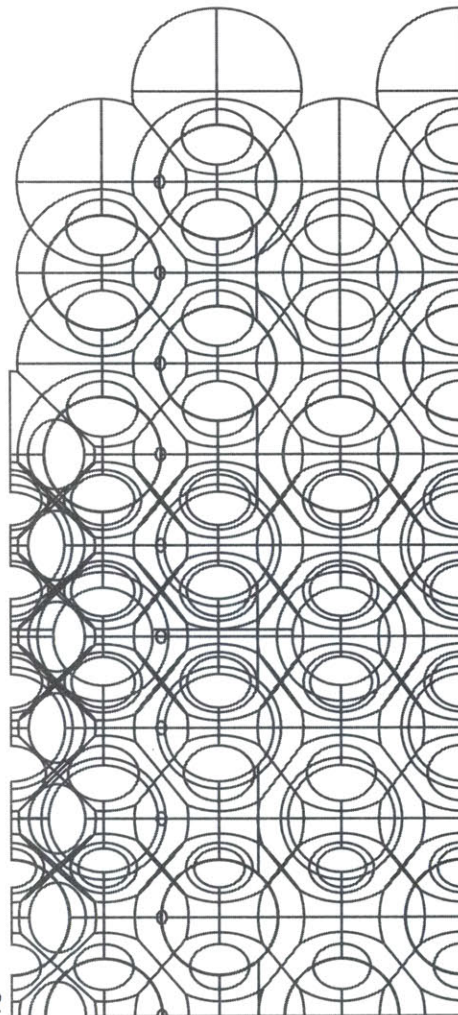




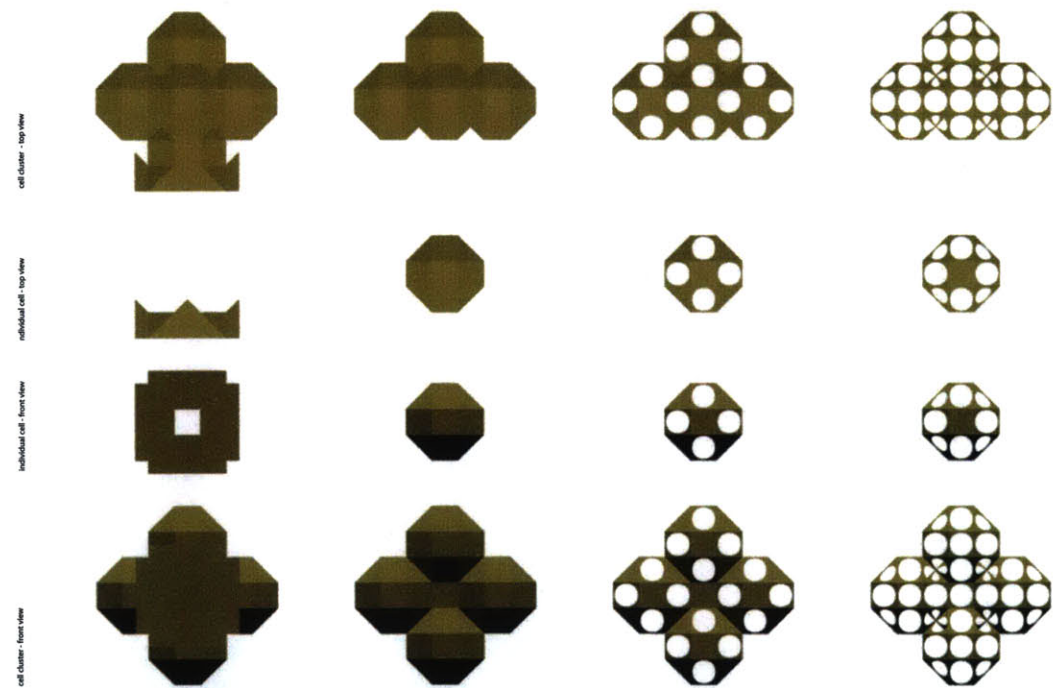
While the idea that the system can react to environmental influences is an important aspect of this project, it is not the focus. The main focus is to design and fabricate a series of component based systems that have the potential to transform if necessary. After considering the time frame for this project, I felt that this needed to be done in order to thoroughly resolve issues dealing with the joinery of the systems components.

configuration studies

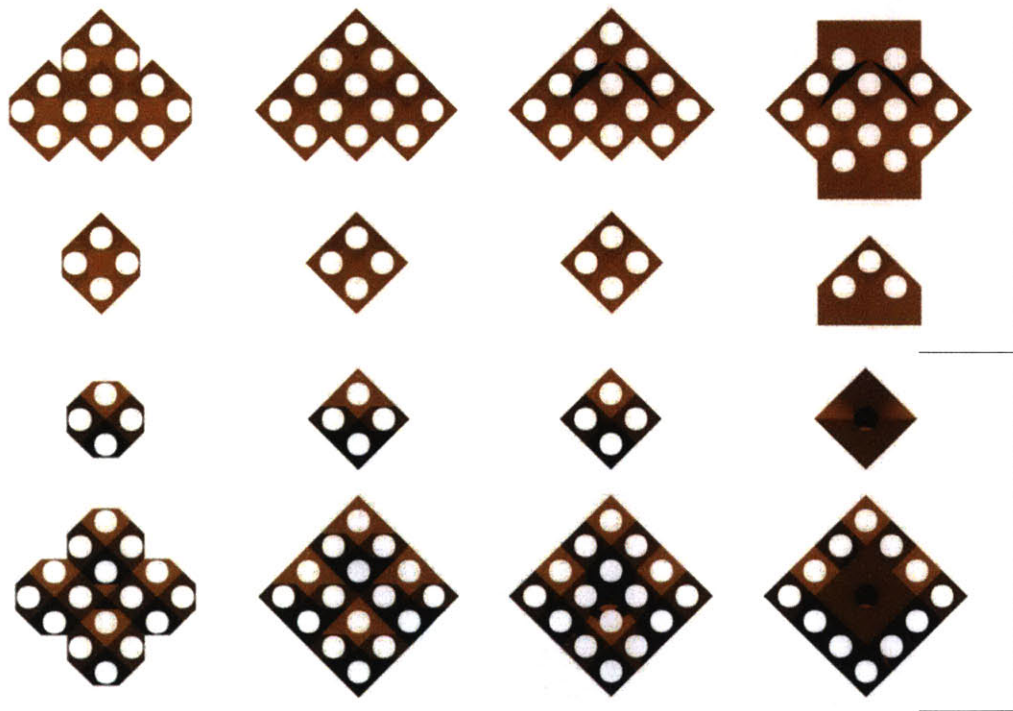
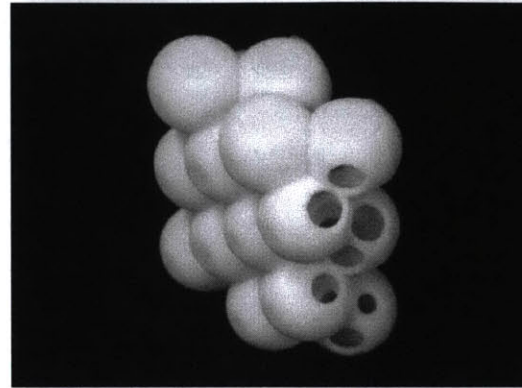
Rhombic Octoheron



3D Unit Diagrams



Dodecahedron

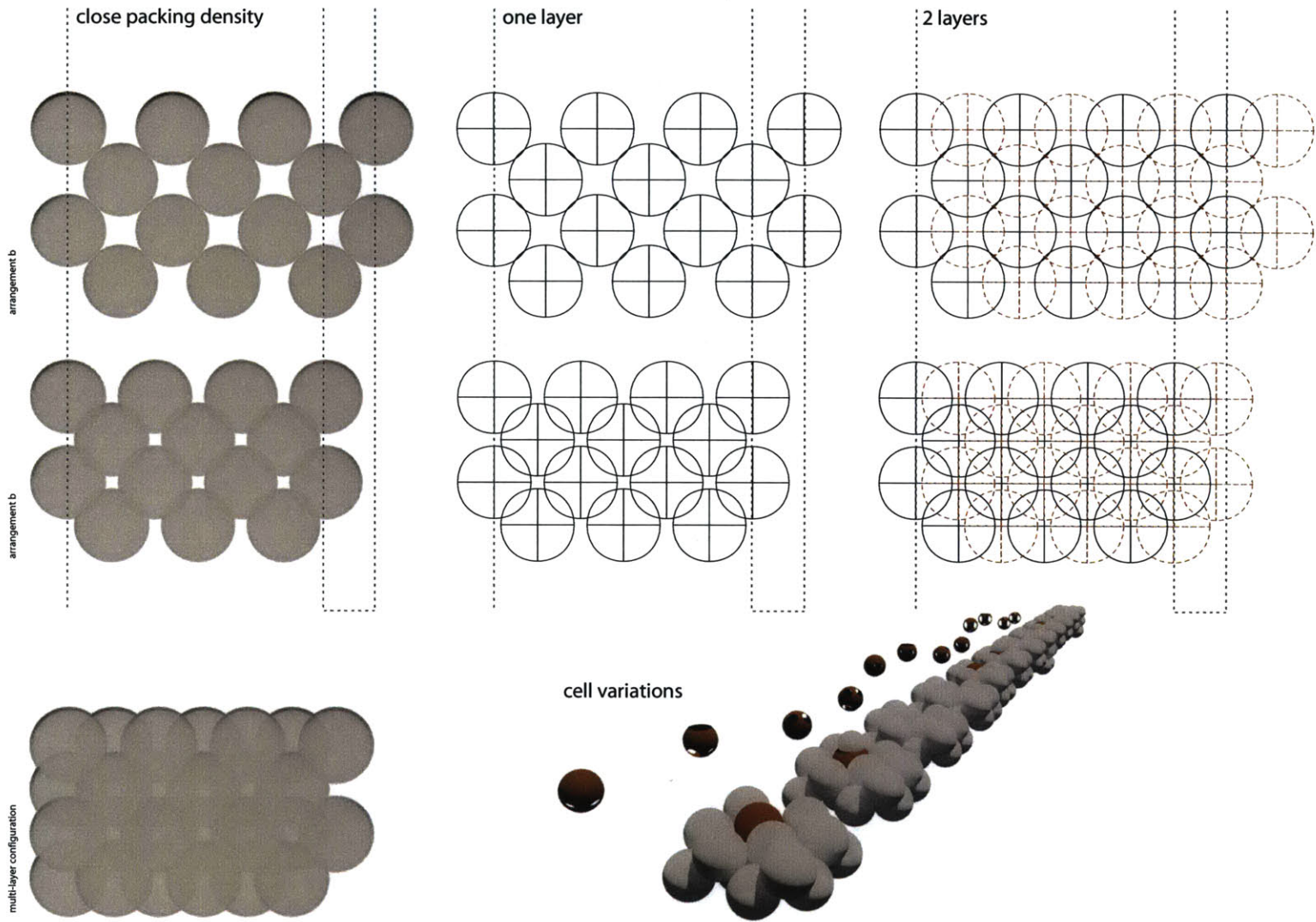


Maximum Diversity Systems

"Technological Man's Pervasive Reliance upon Standardization undifferentiated form minimizes the possibility for diversity. We need to develop a building strategy with which diversity and change can be accomplished by modular systems which are efficient in their use of natural materials and energy resources"

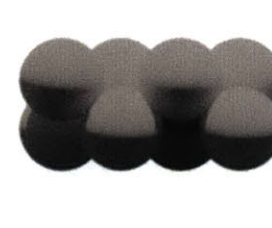
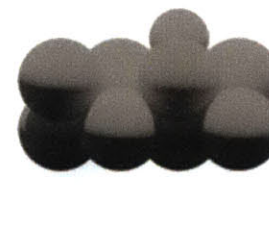
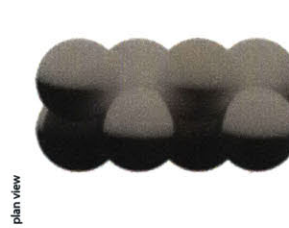
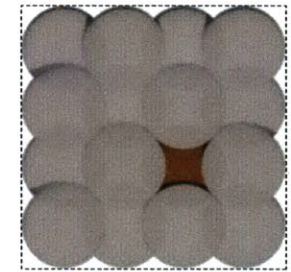
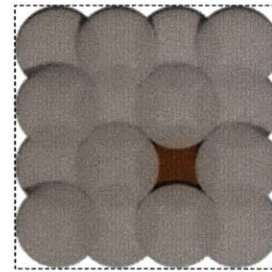
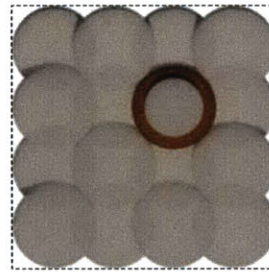
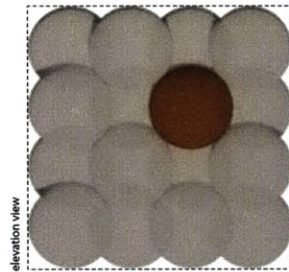
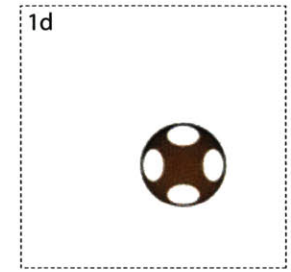
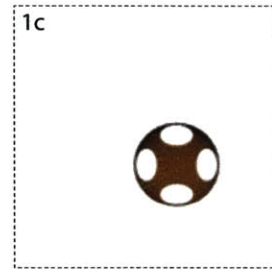
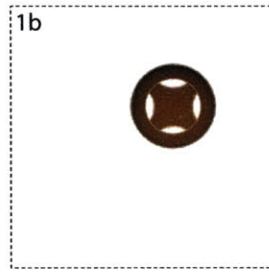
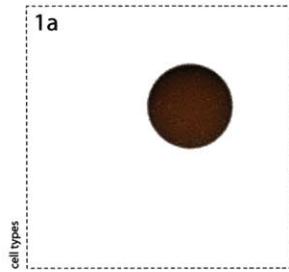
-Peter Pearce

Cellular patterning



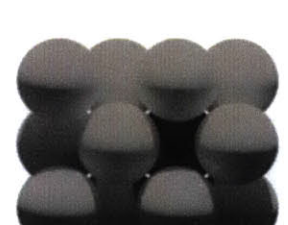
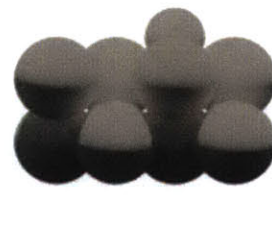
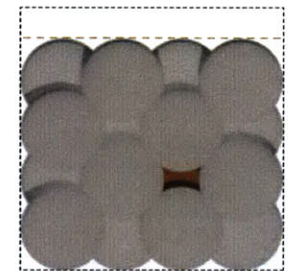
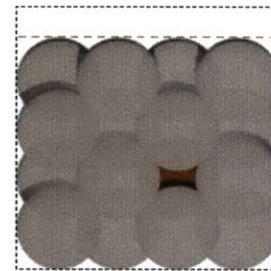
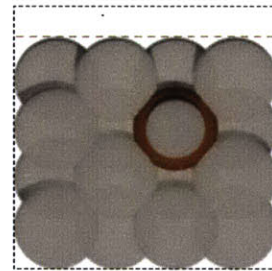
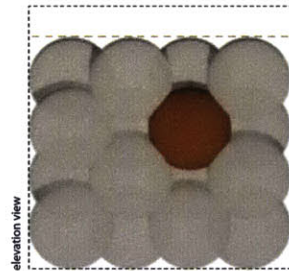
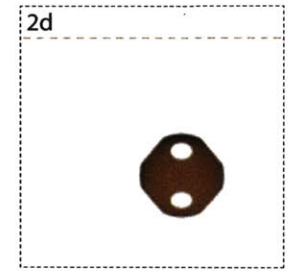
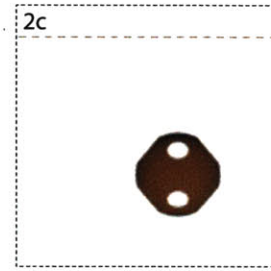
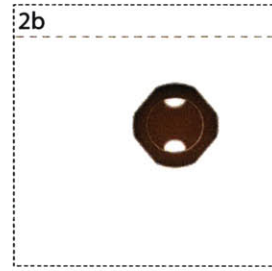
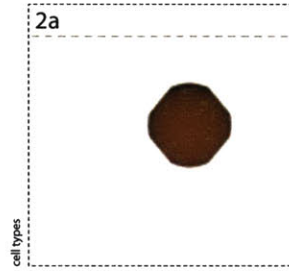
Cellular Variations

type 1



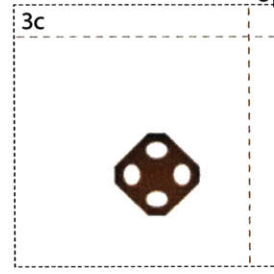
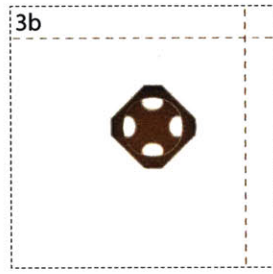
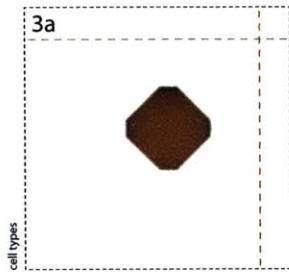
Cellular Variations

type 2

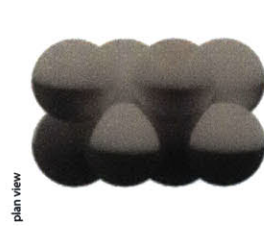
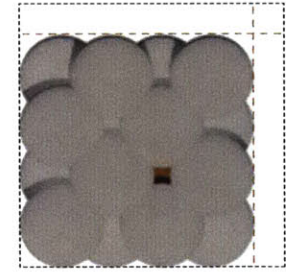
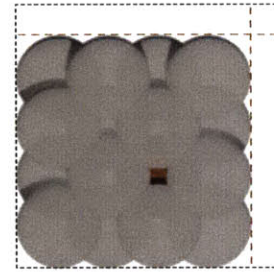
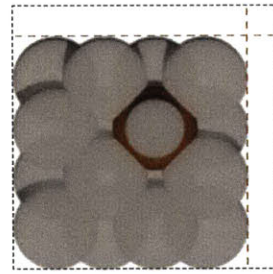
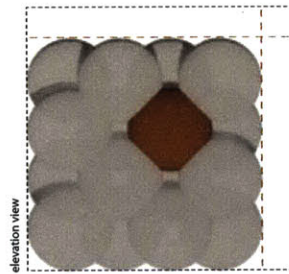
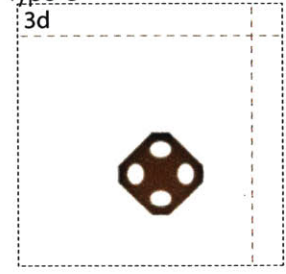


Cellular Variations

type 3

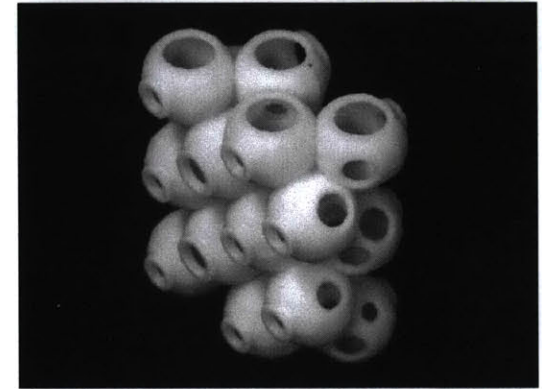


Sphere Cell Type 3

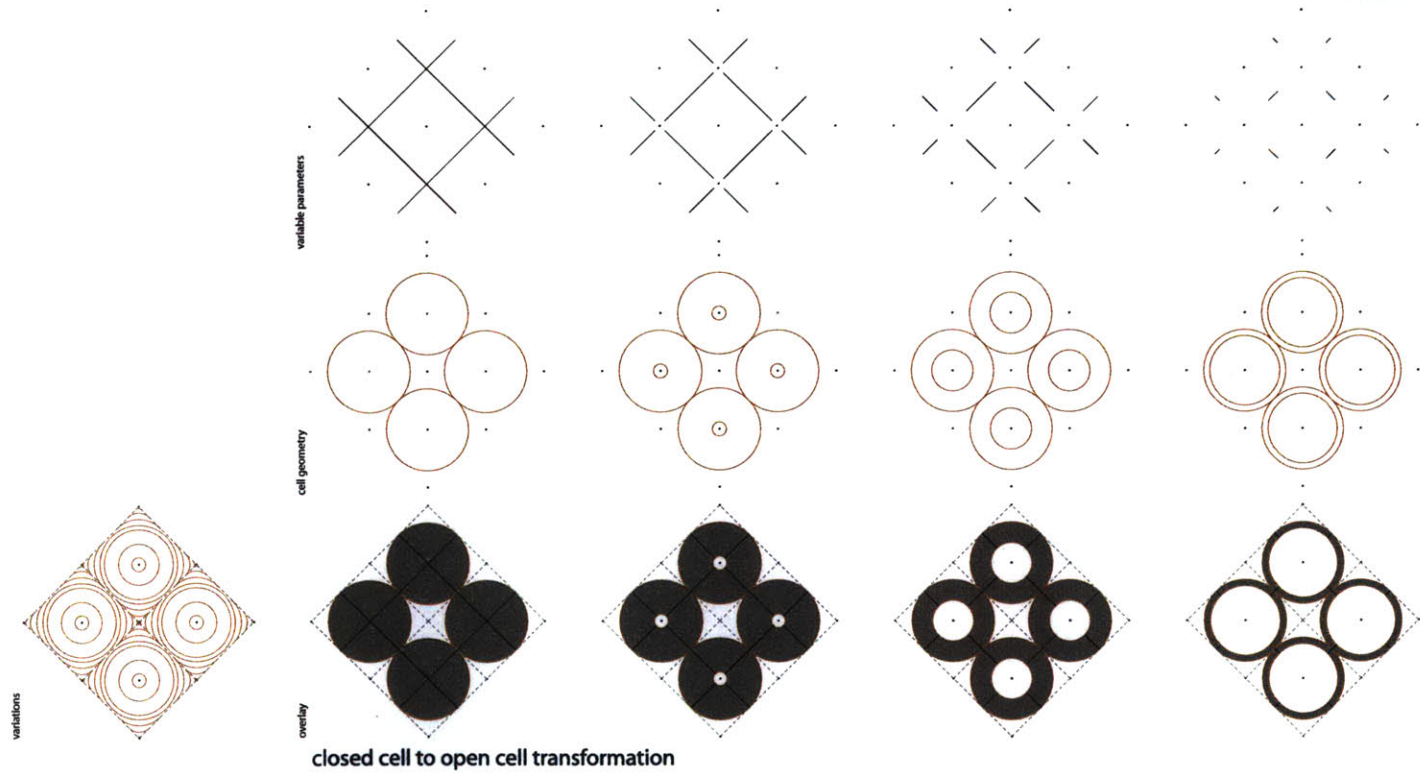


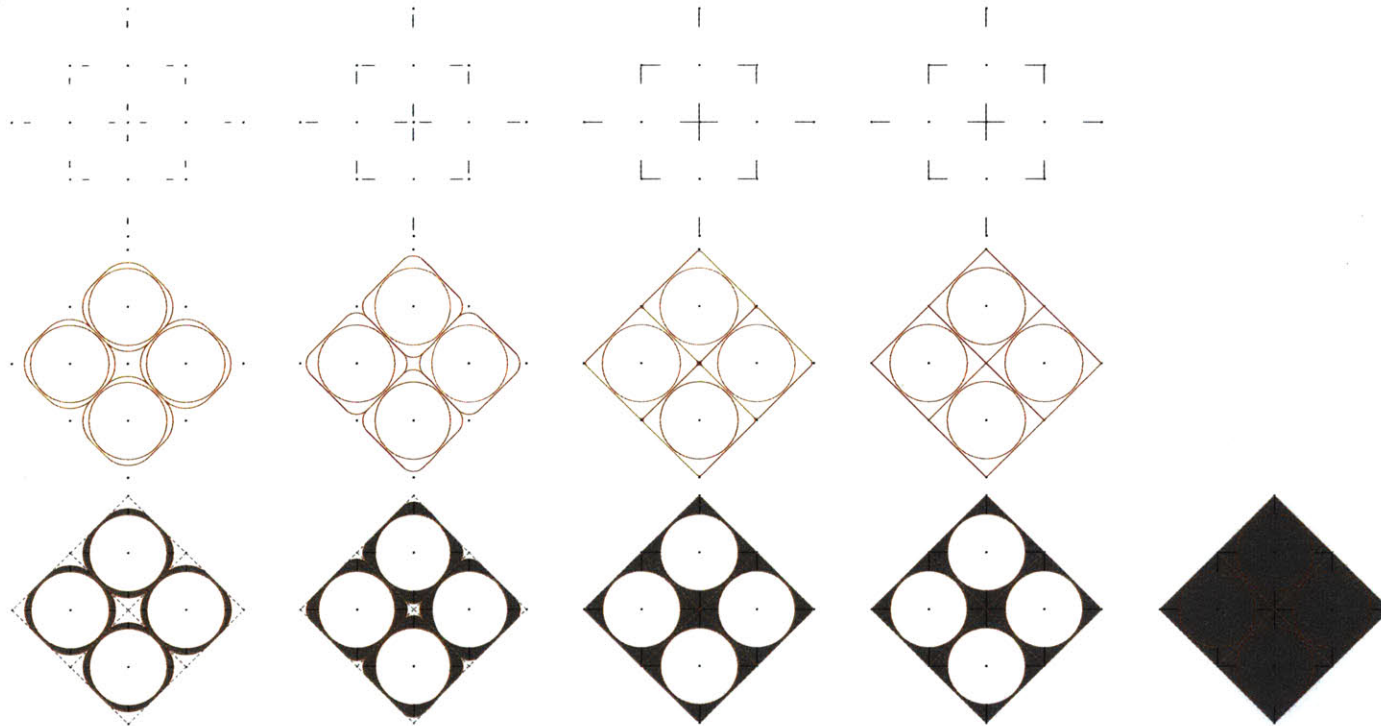
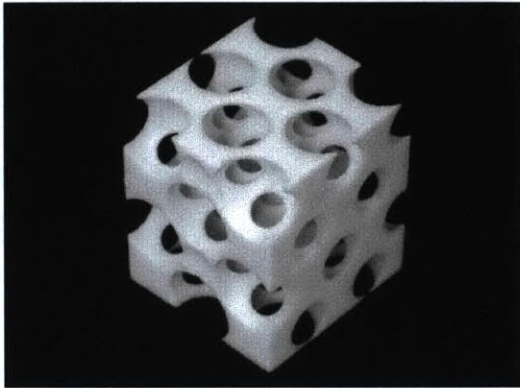
Topological Transformations

The following diagrams illustrate how the system can transition from a spherical shaped module to a square shaped one.



Sectional Diagrams

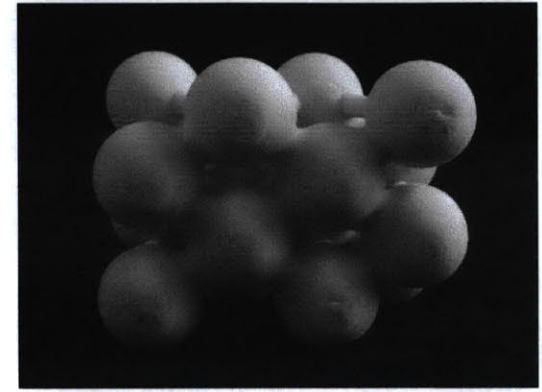




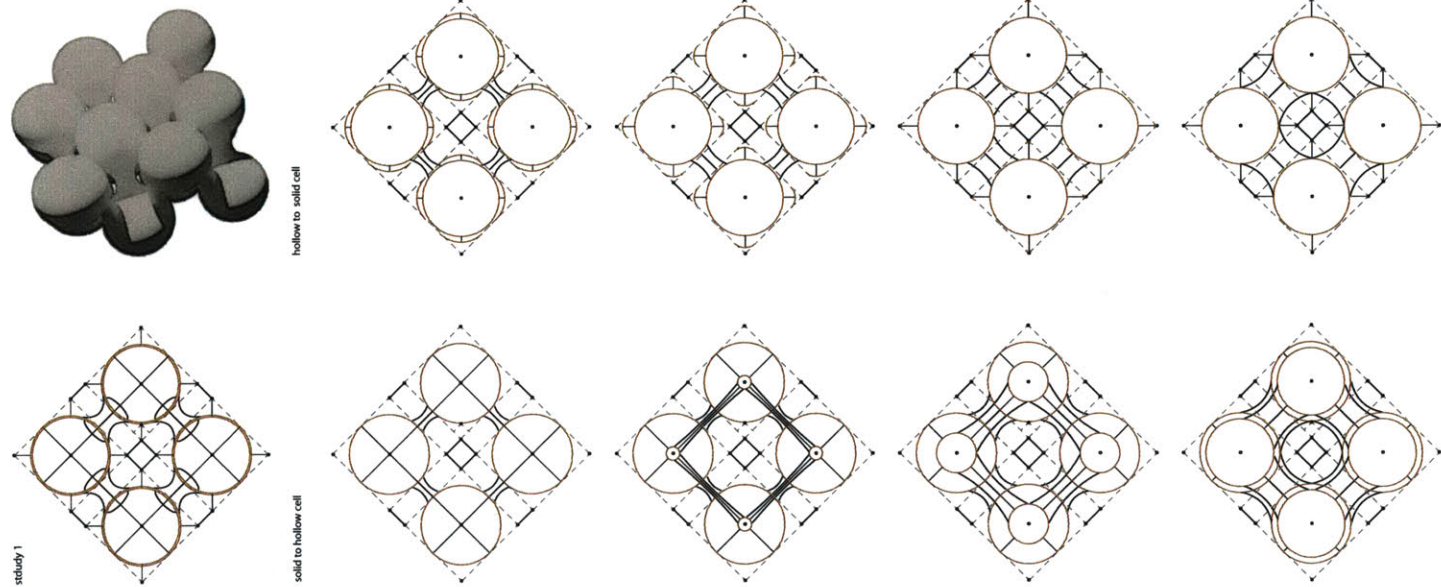
cell to space frame transformation

Topological Stretching

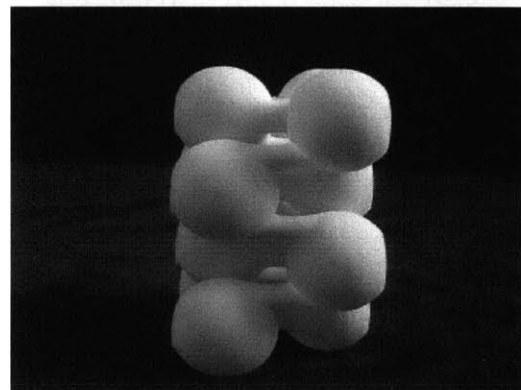
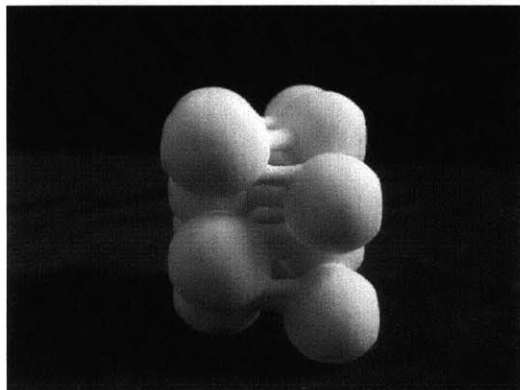
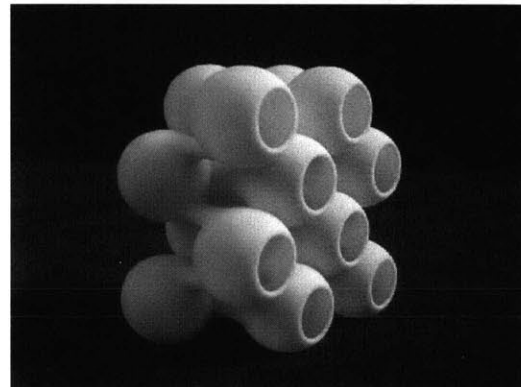
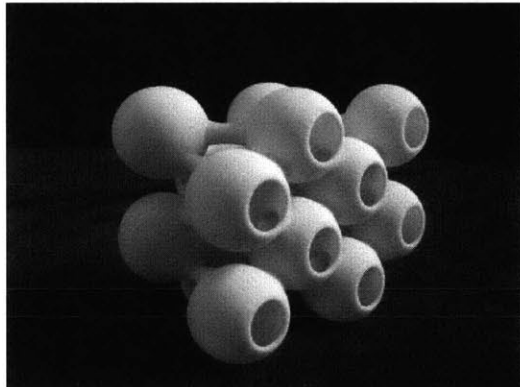
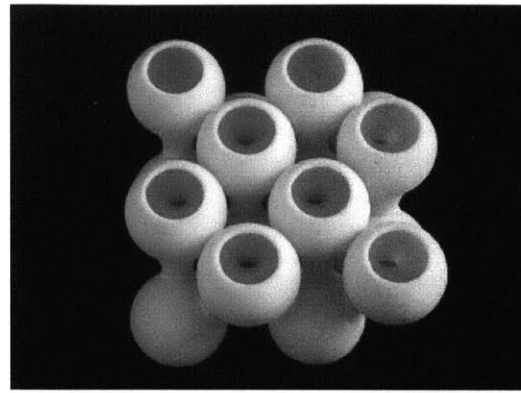
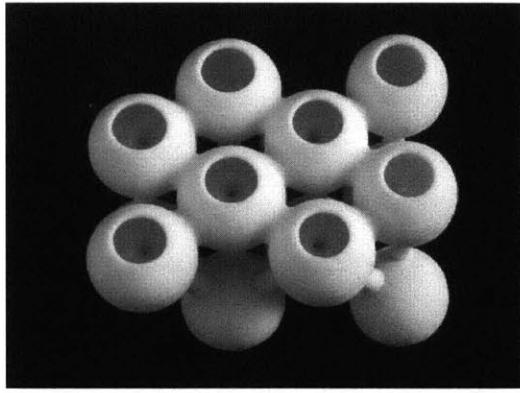
Pulling the cells away from one another creates a connective tube. This act creates a secondary spatial cavity between the cells.



Configuration Diagram 2



basic cell assembly

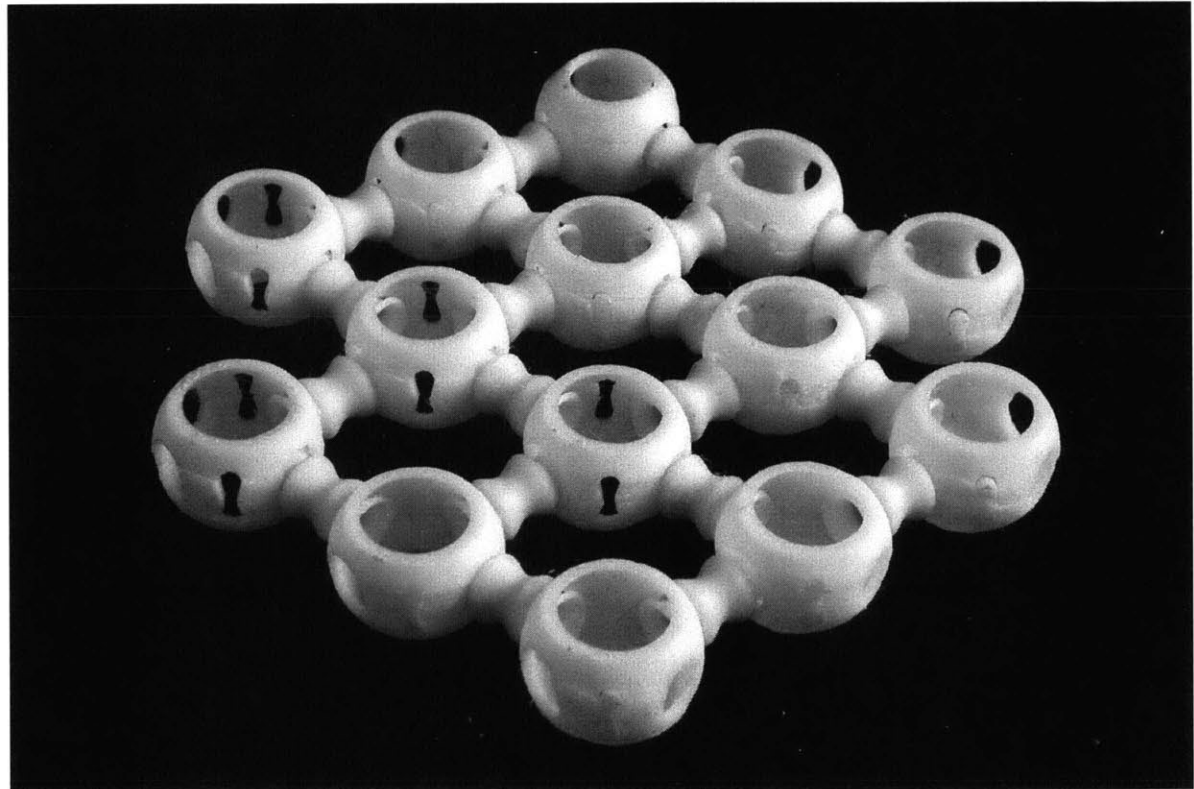
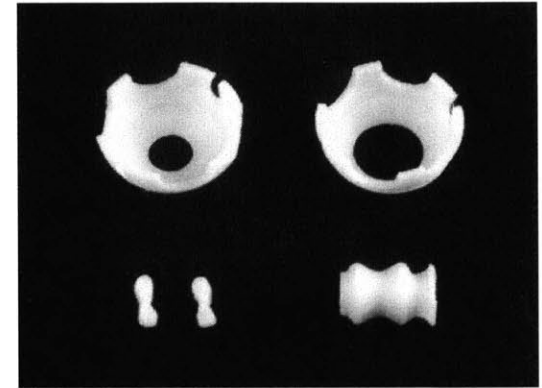


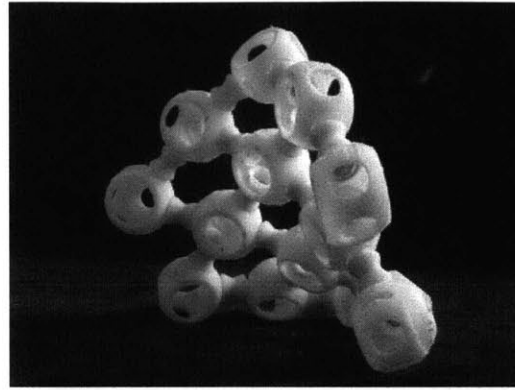
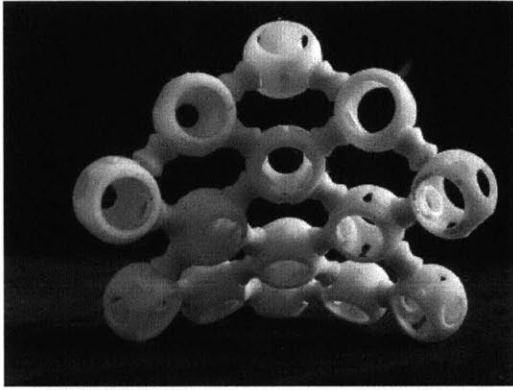
Spatial Patterning

This investigation aspires to deploy patterns spatially for the purpose of exploiting variable thickness and surface articulation to escape superfluous redundancy and also to develop a closer relationship between structural configuration and localized variation in modes of occupation and program.

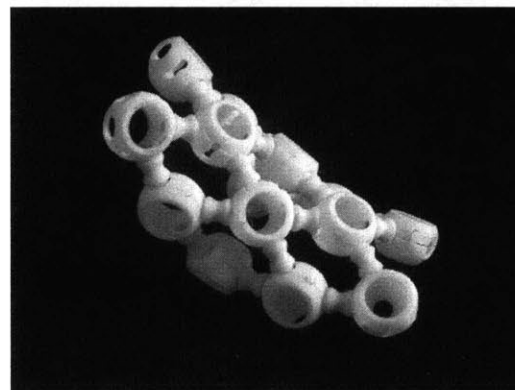
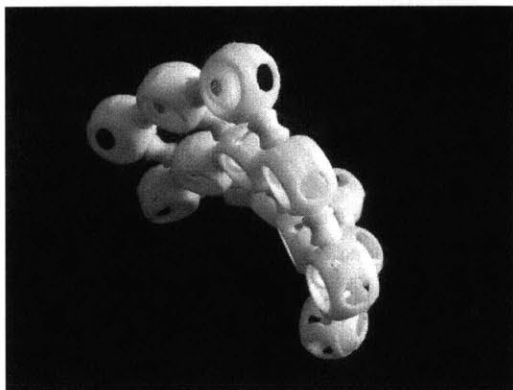
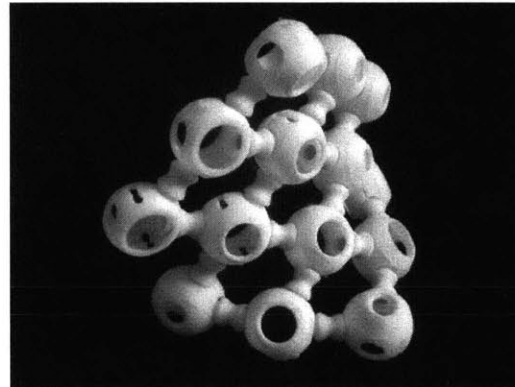
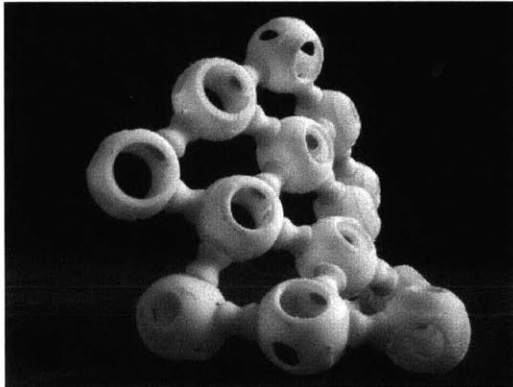
Curvature with Zero Deformation

This objective of this model was to create a system that could allow for some curvature without any deformation to the cellular component.

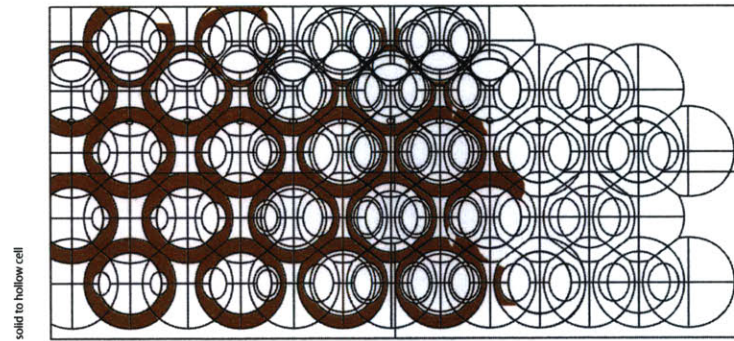
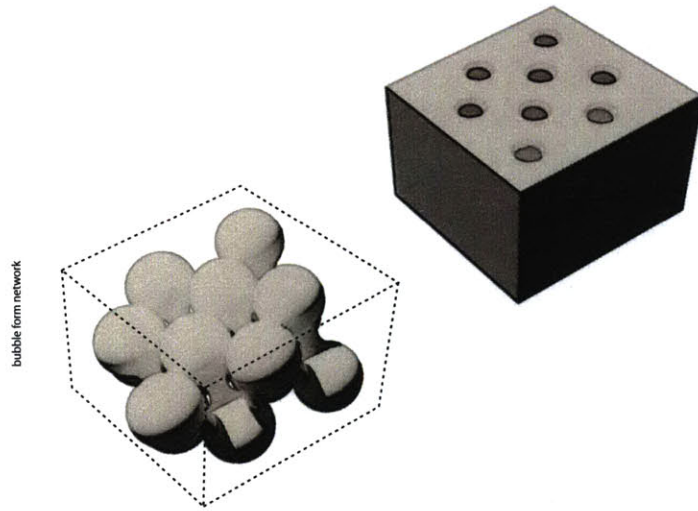




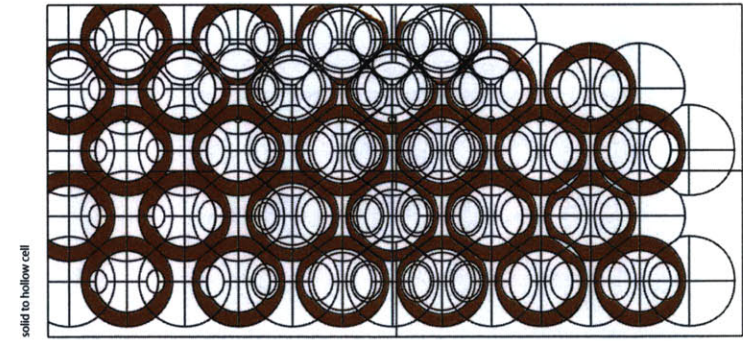
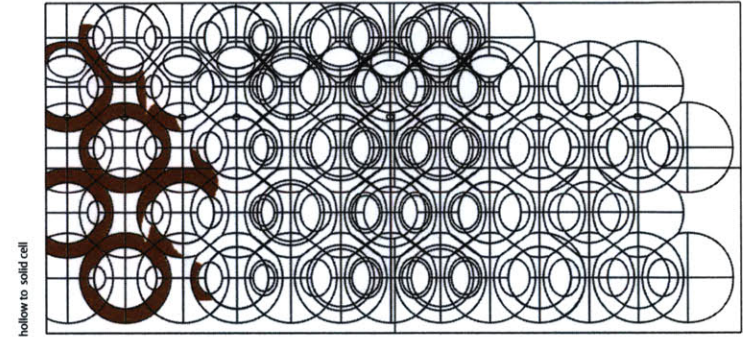
Spatial Variations

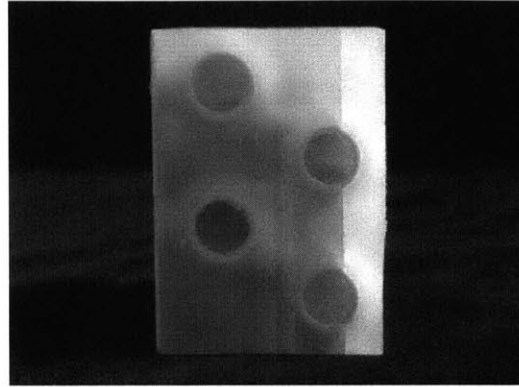
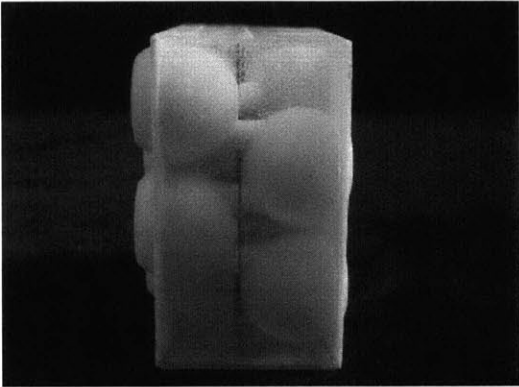


Embeded formwork



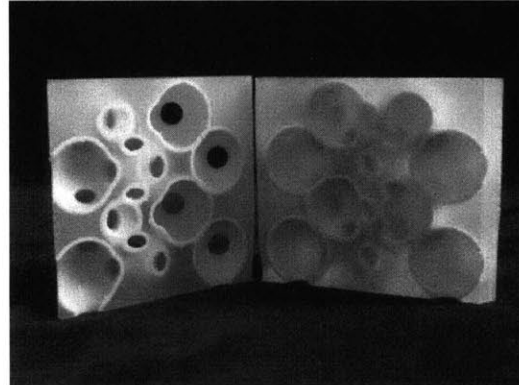
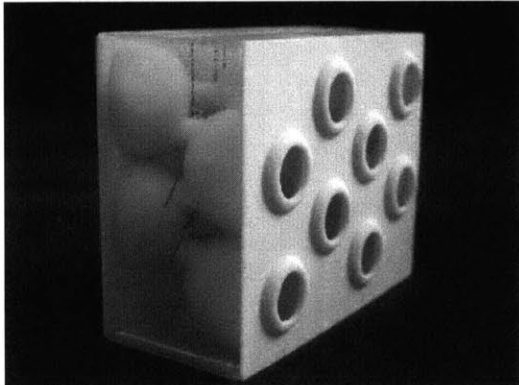
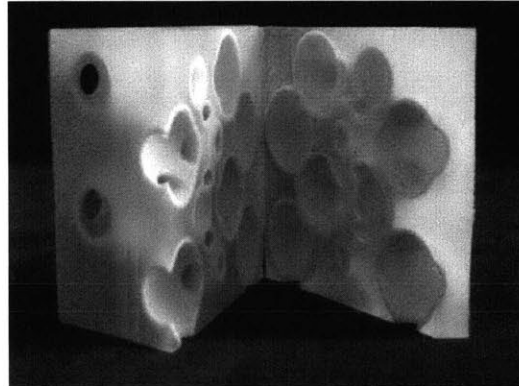
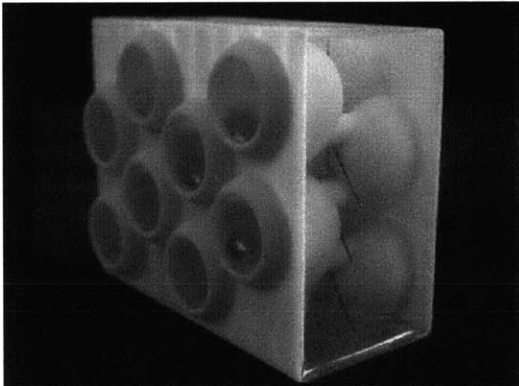
double cavity manifold





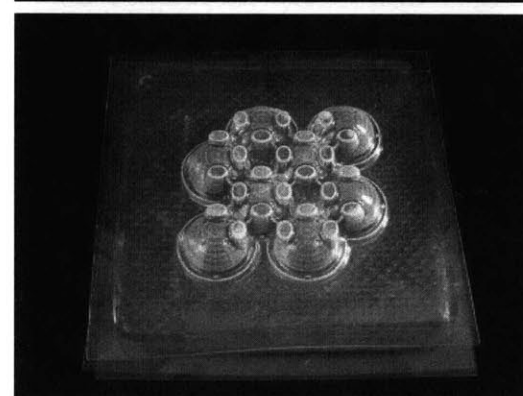
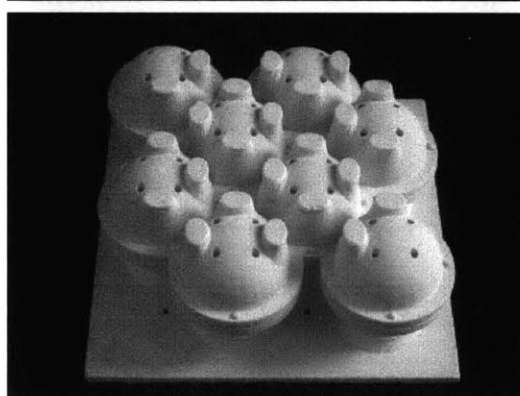
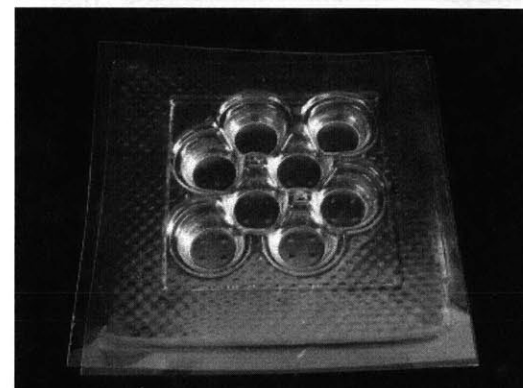
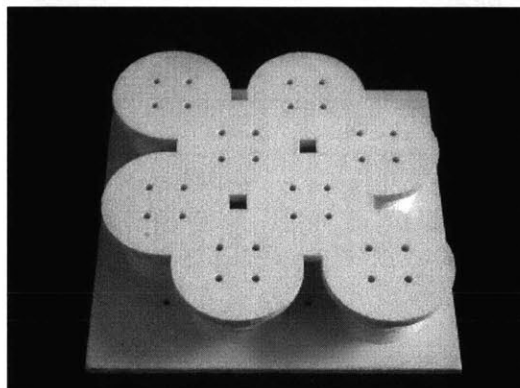
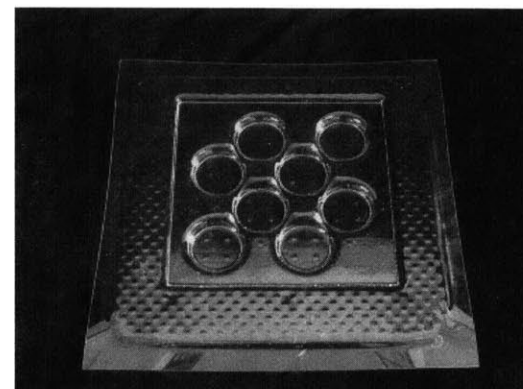
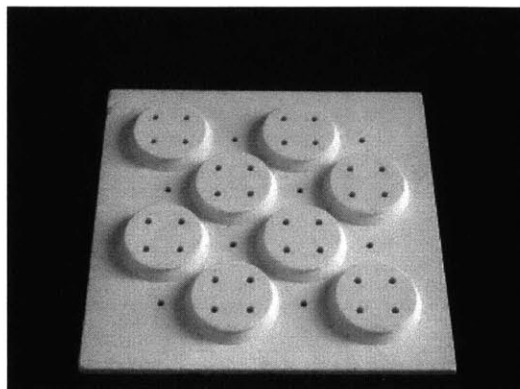
Secondary Spatial Cavity

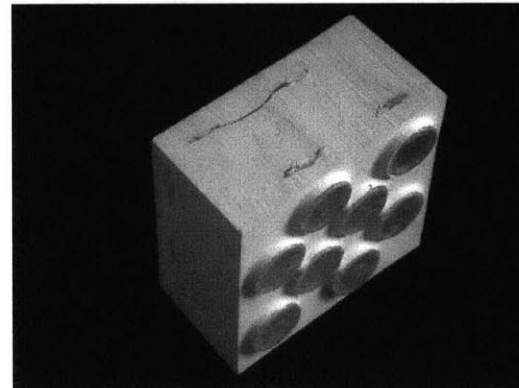
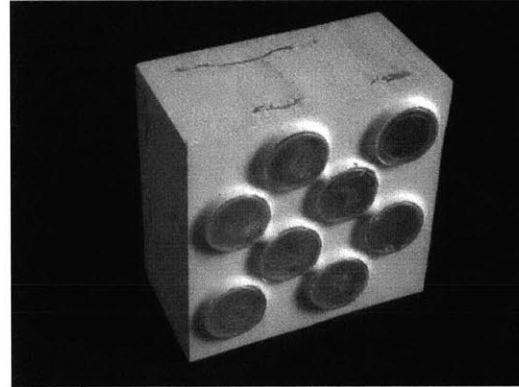
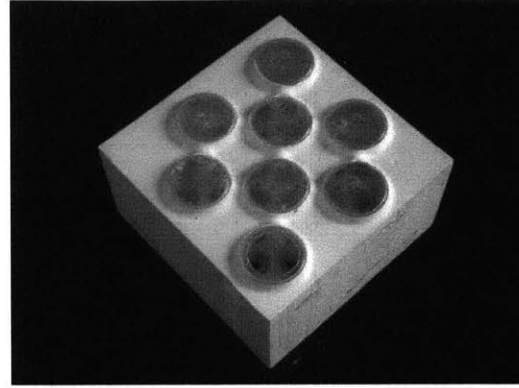
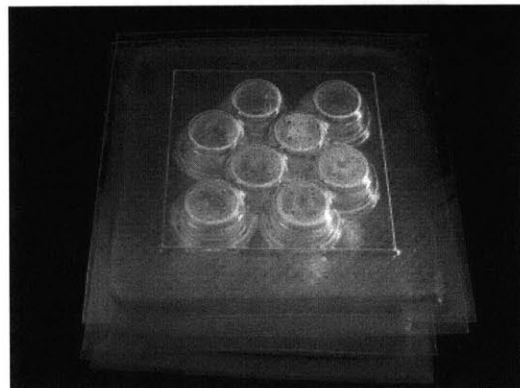
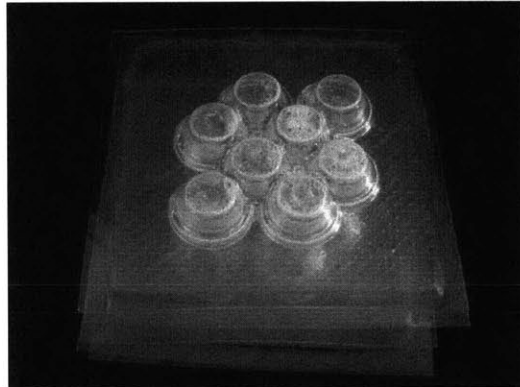
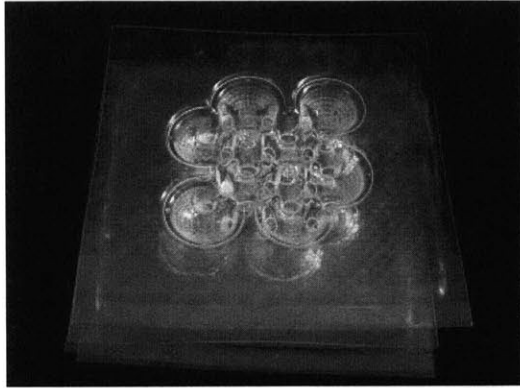
This model illustrates the space between the cells. This secondary space can be used to house infrastructure such as electricity or plumbing.



Sectioned Form Work

By slicing a network of spheres into sets, I was able to vacume-form around the sections to create a form work.



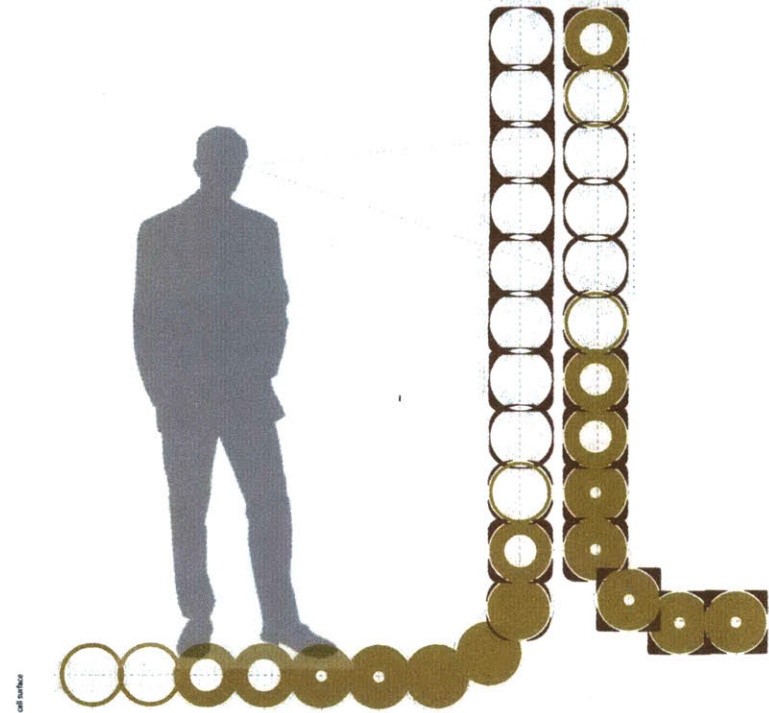
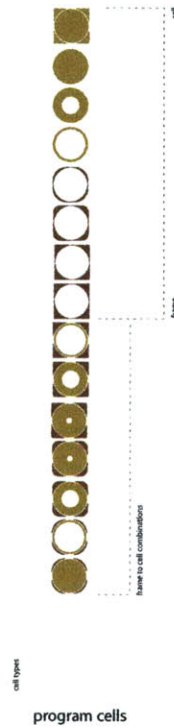
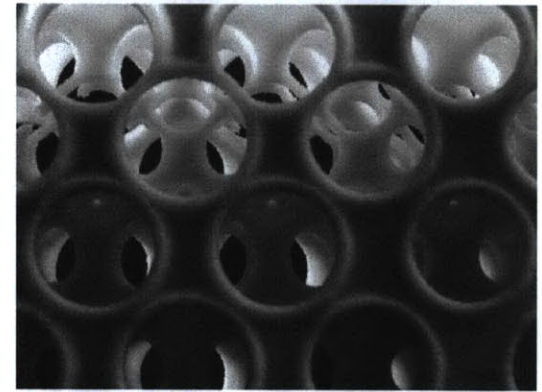
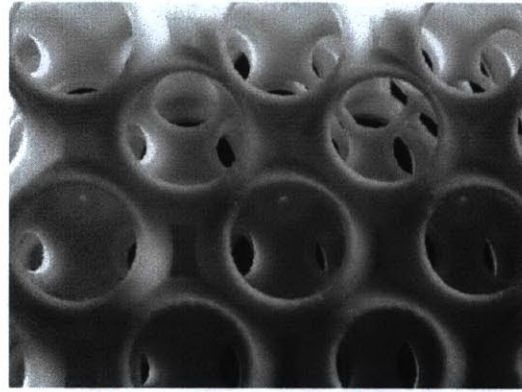


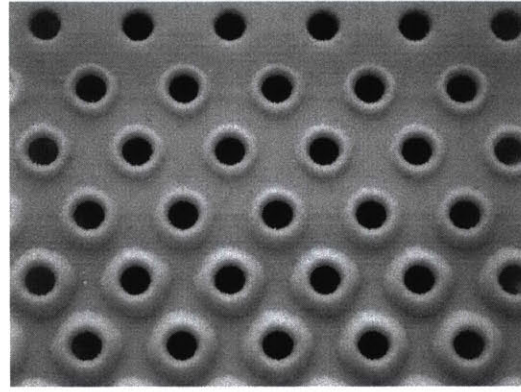
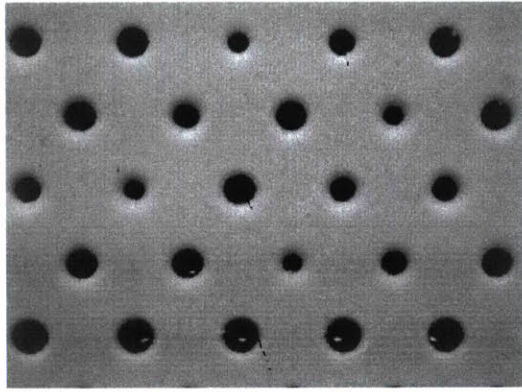
Embedded From Work

After configuring the sections together, I was able to cast plaster around the plastic forms.

Programmatic Patterning

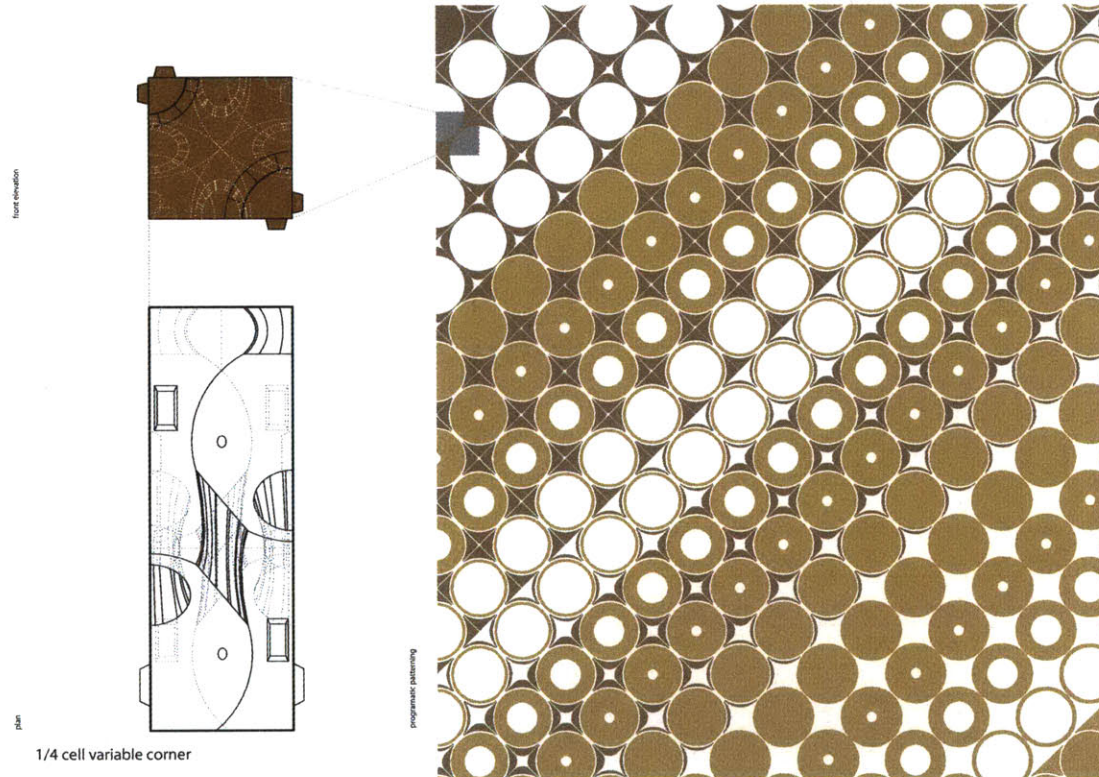
By varying the porosity of the individual cell, it is possible to create more visual transparency through an arrangement of cellular components.



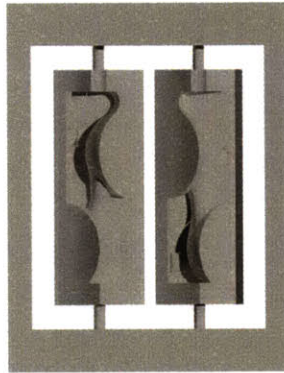


Programatic Patterning

Configuration of the cells can be done through programatic rather than visual patterning.

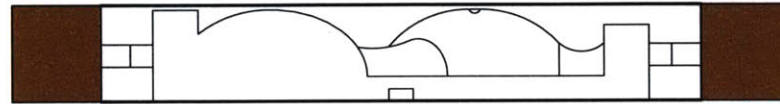


Cast Cell Unit 1

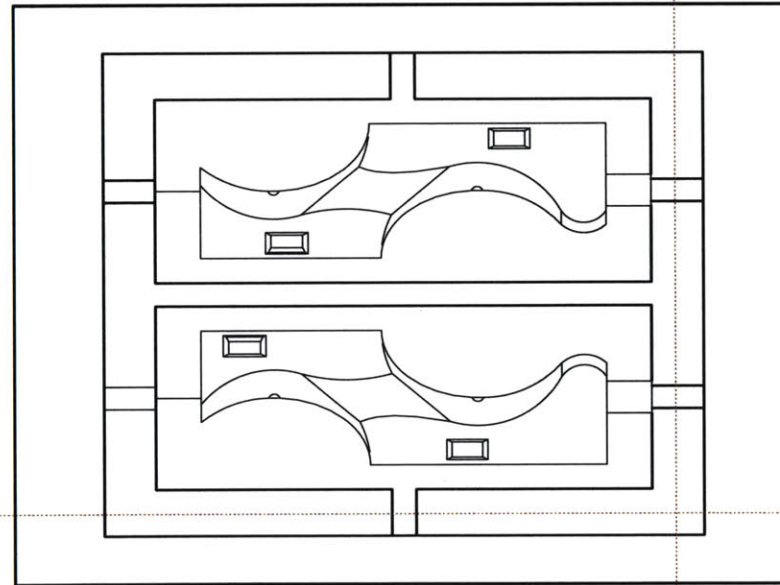


1/4 cell milled formwork

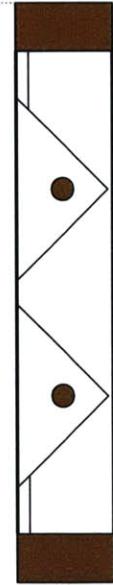
section a



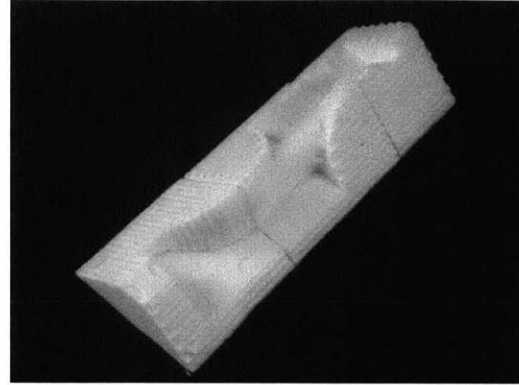
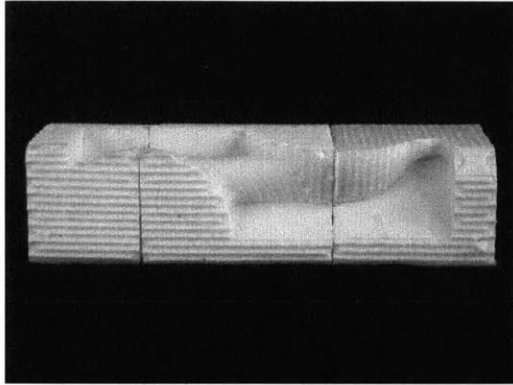
top view



section b

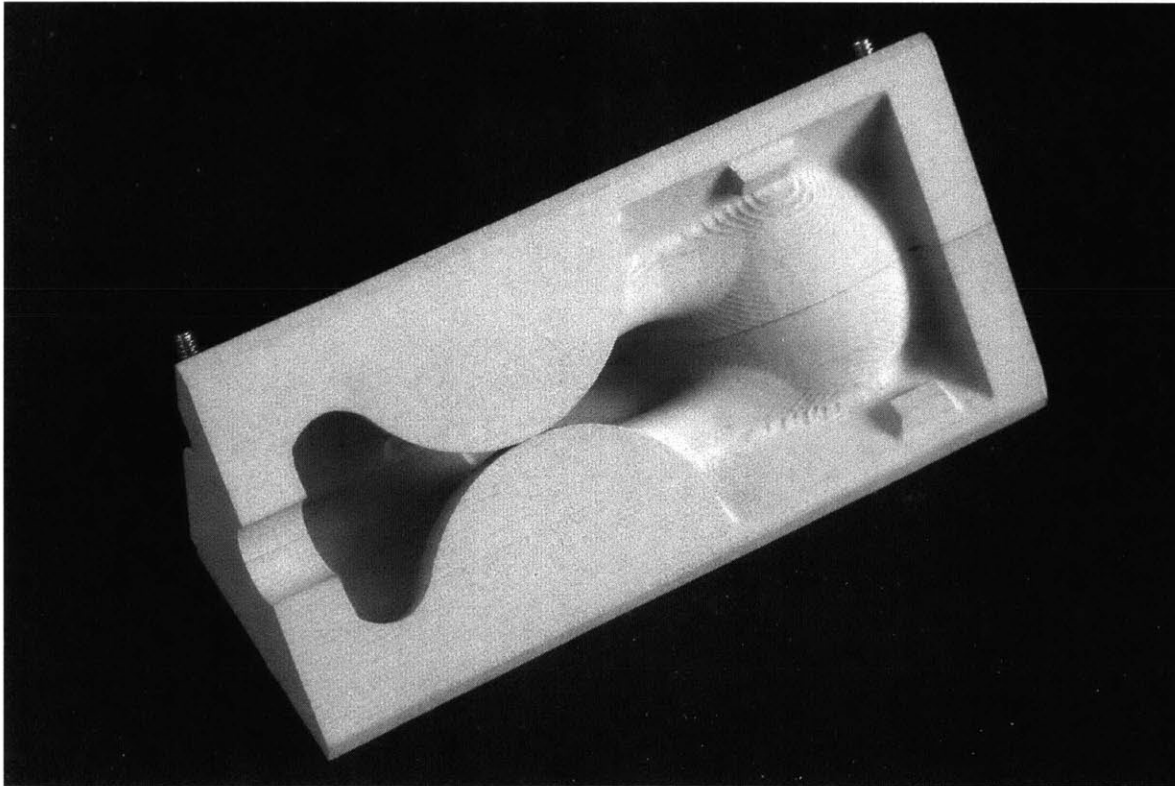


section b

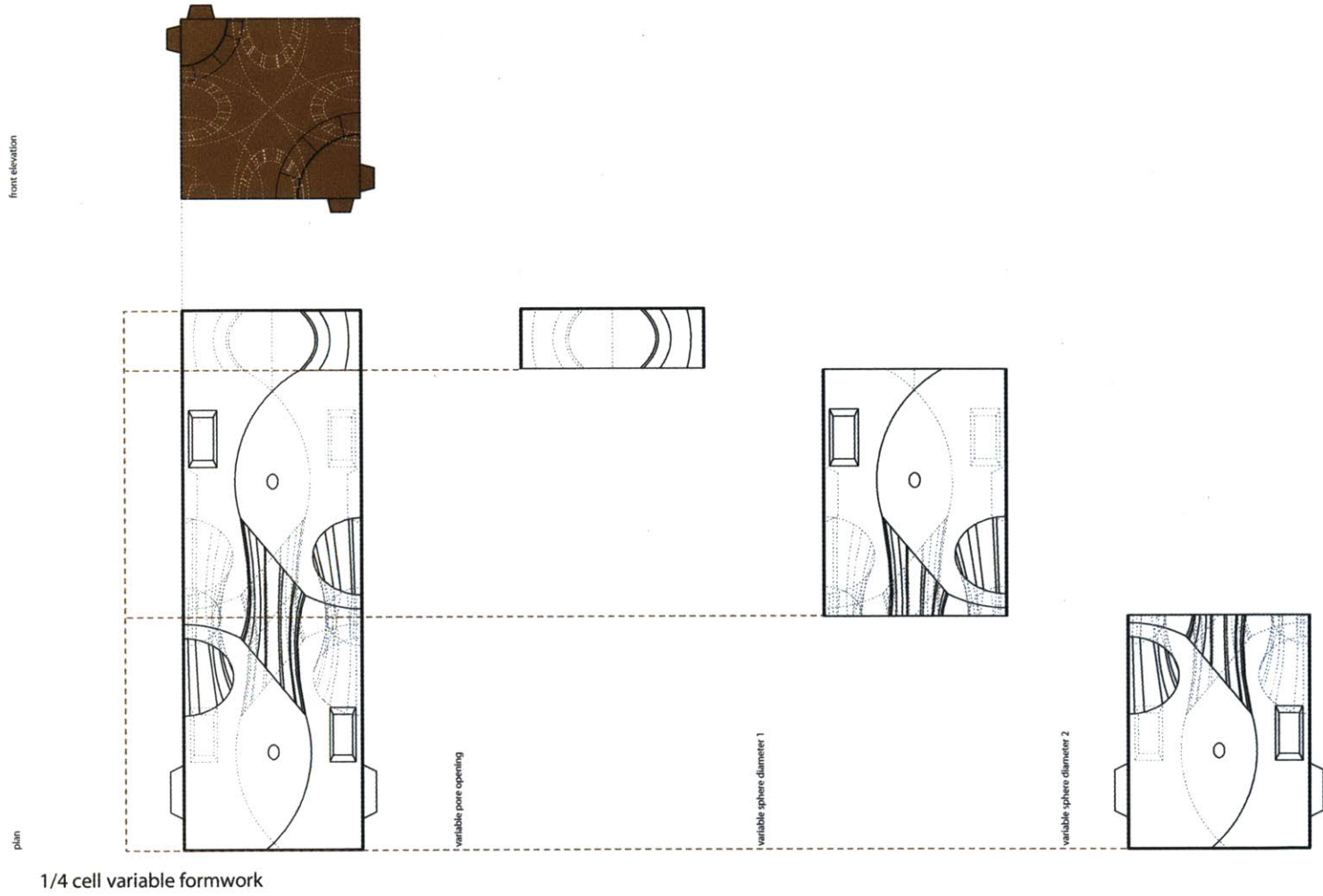


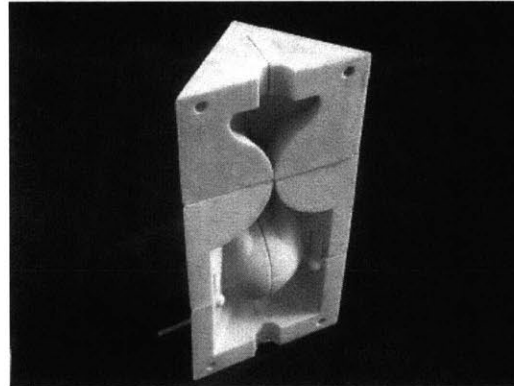
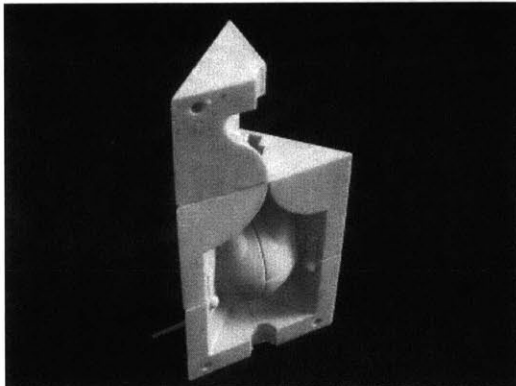
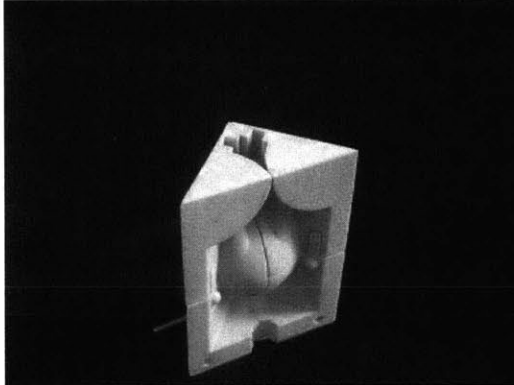
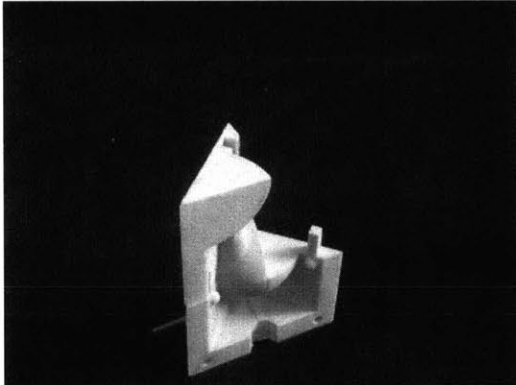
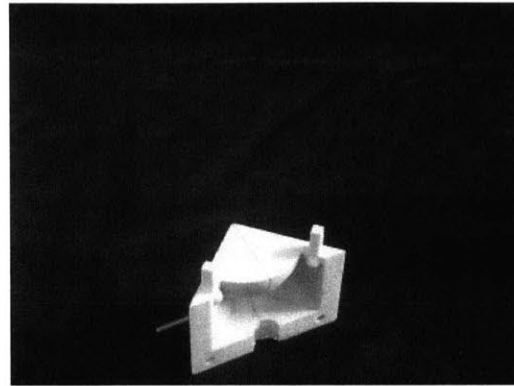
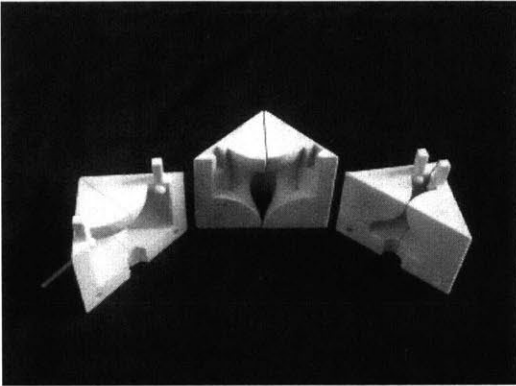
Sectioned Unit Cell Form Work

It is possible to create a porous network by subdividing the complex shapes into small sections. This image illustrates an example of a sectioned cell form work.



Cast Cell Unit 2

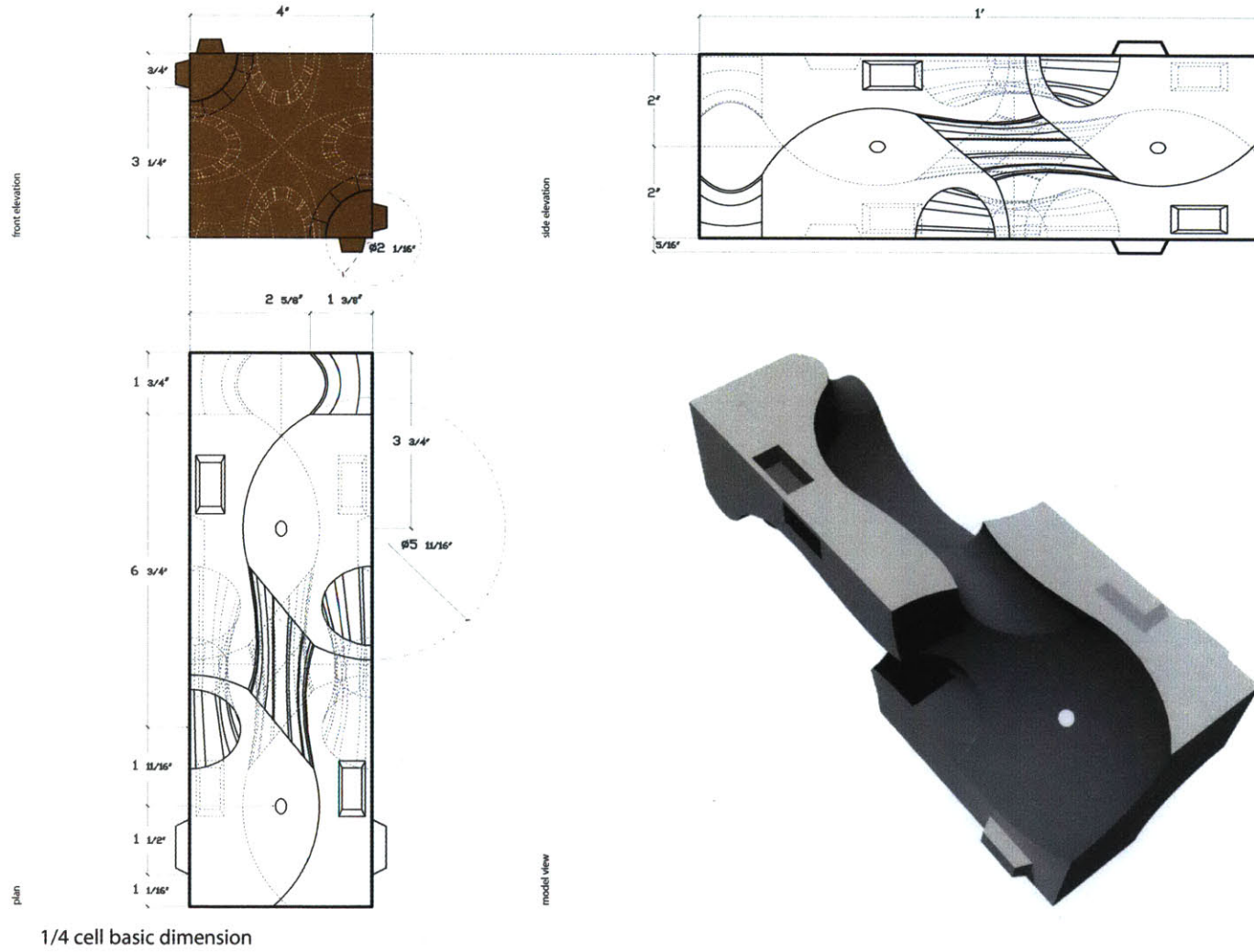




Sectioned Form work

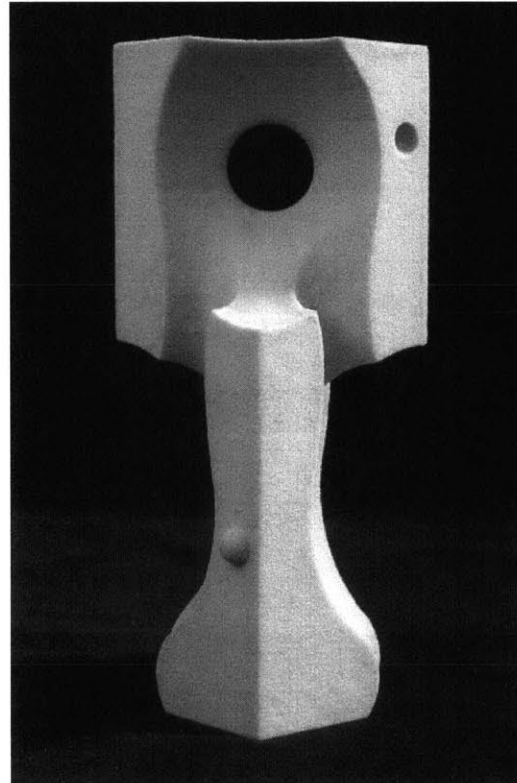
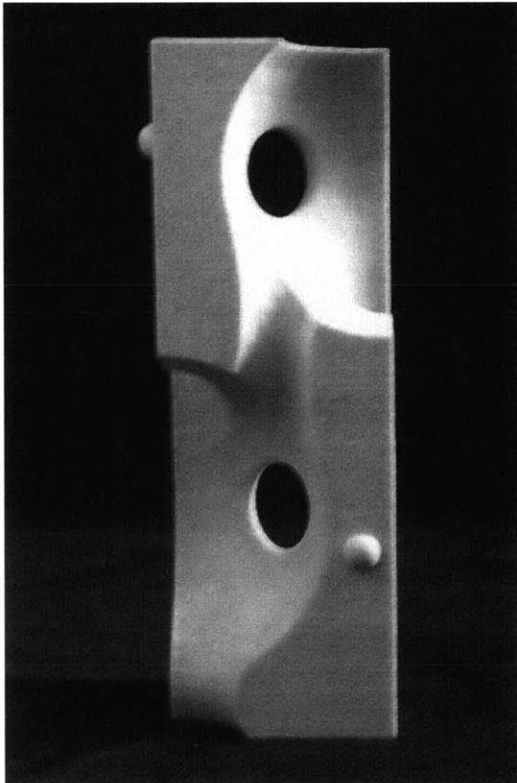
By subdividing the individual form work into 3 sections, you can create a larger variation of cell types by recombining the parts. These images illustrate a casting form work that can be reconfigured to create twice as many varied components.

Cast Cell Unit 1



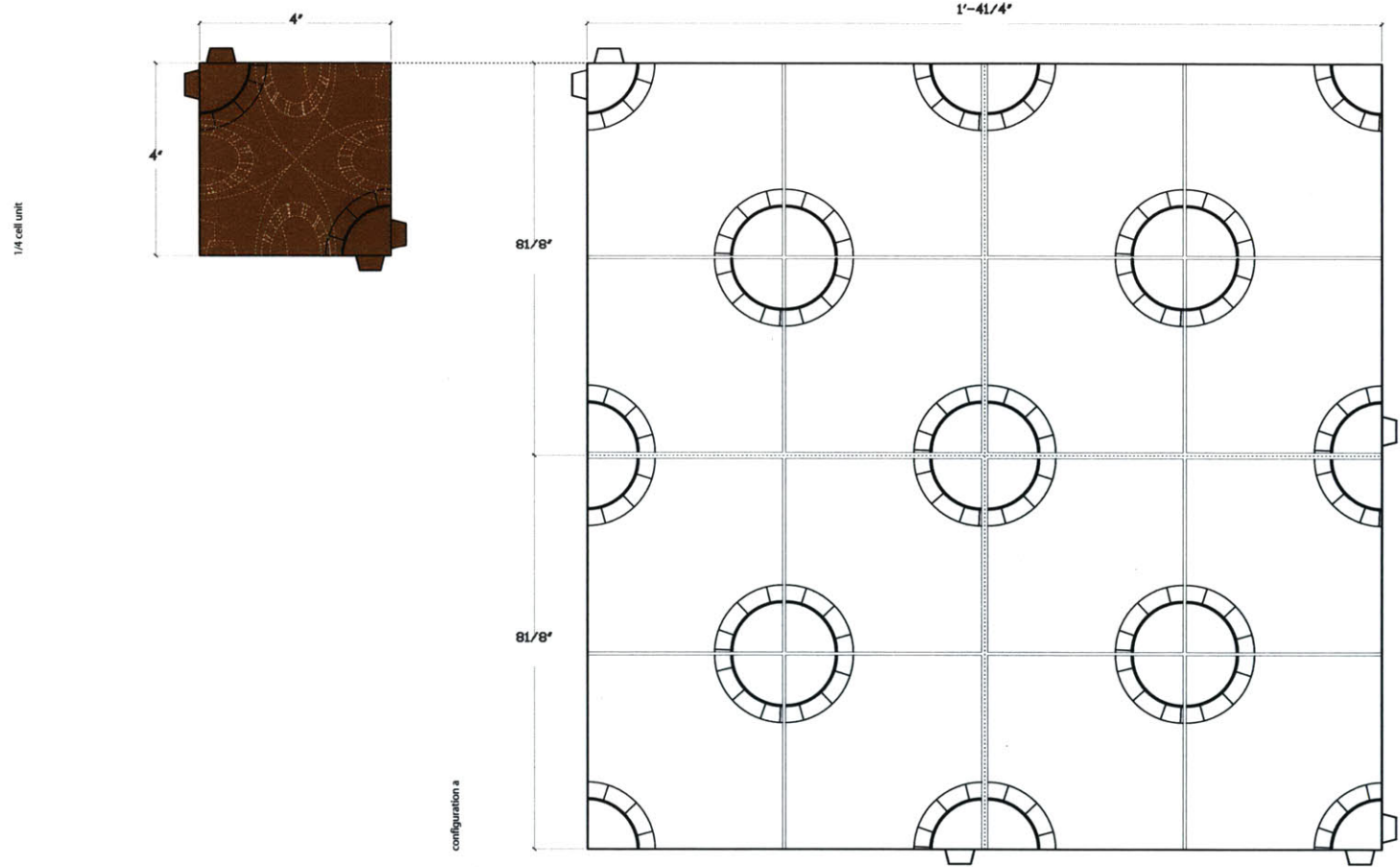
1/4 Cell Unit

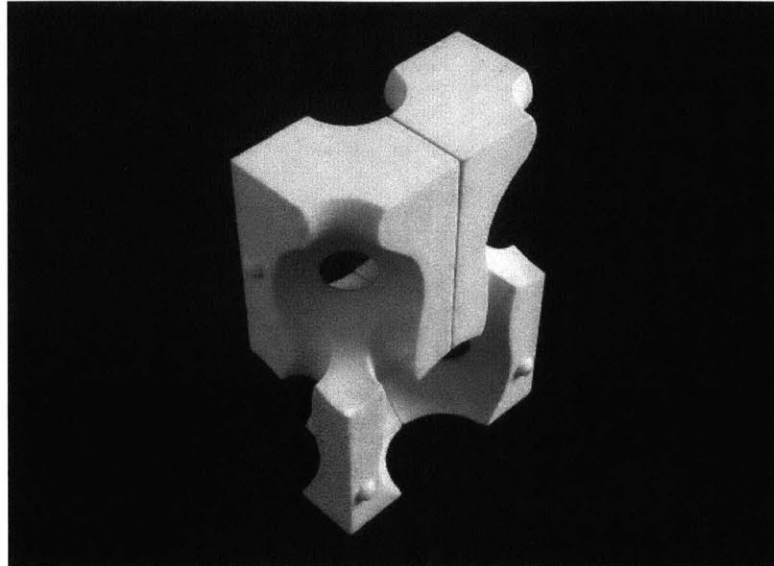
This is an example one cell component to come out of the reconfigurable form work.



Cast Cell Unit 1

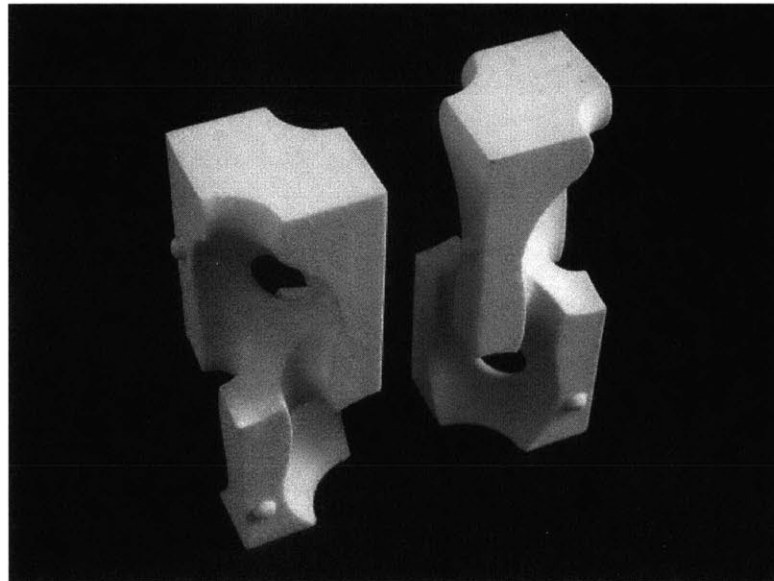
basic cell assembly





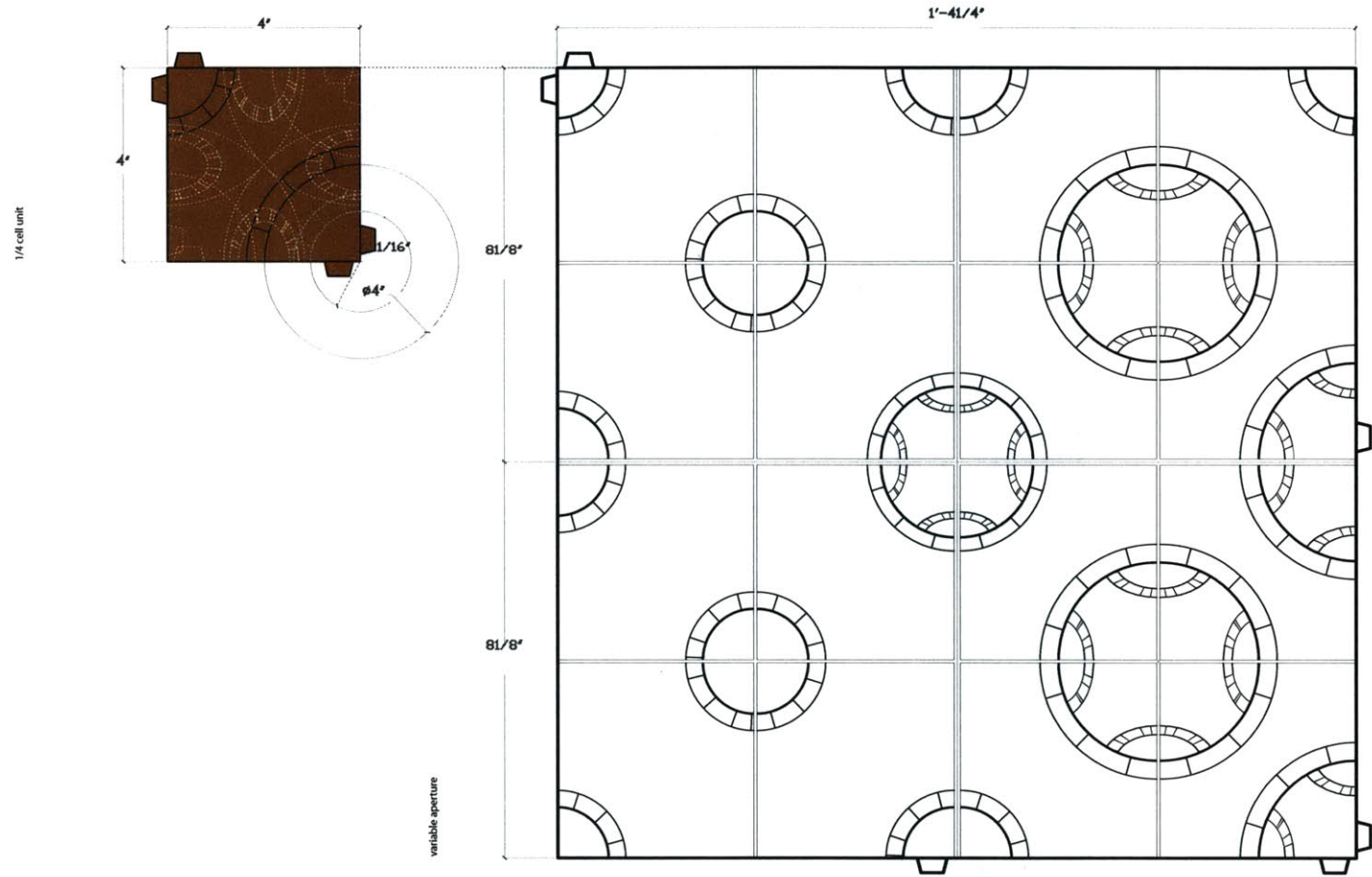
1/4 Cell Unit Assembly

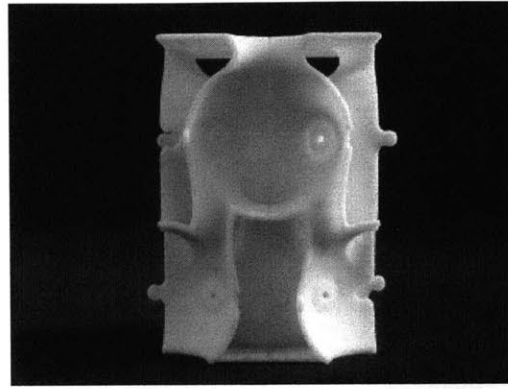
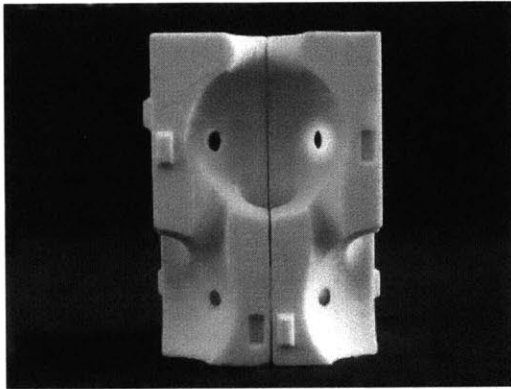
The units can be aggregated to create a larger wall surface.



Cast Cell Unit 1

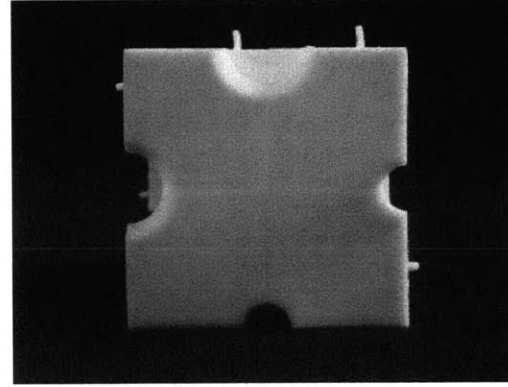
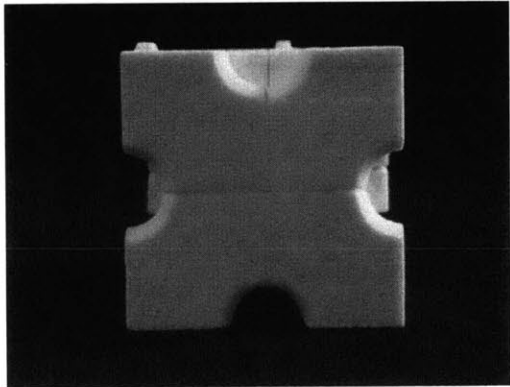
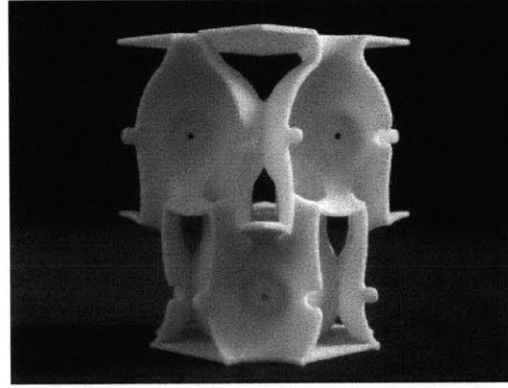
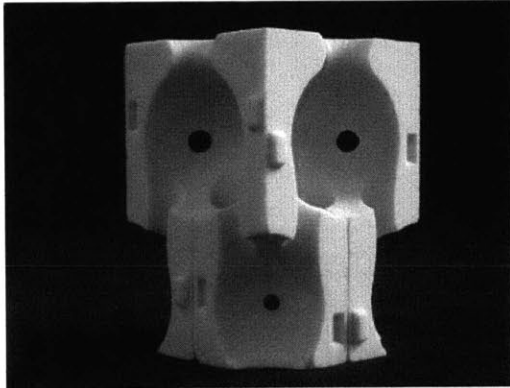
cell variable pore assembly





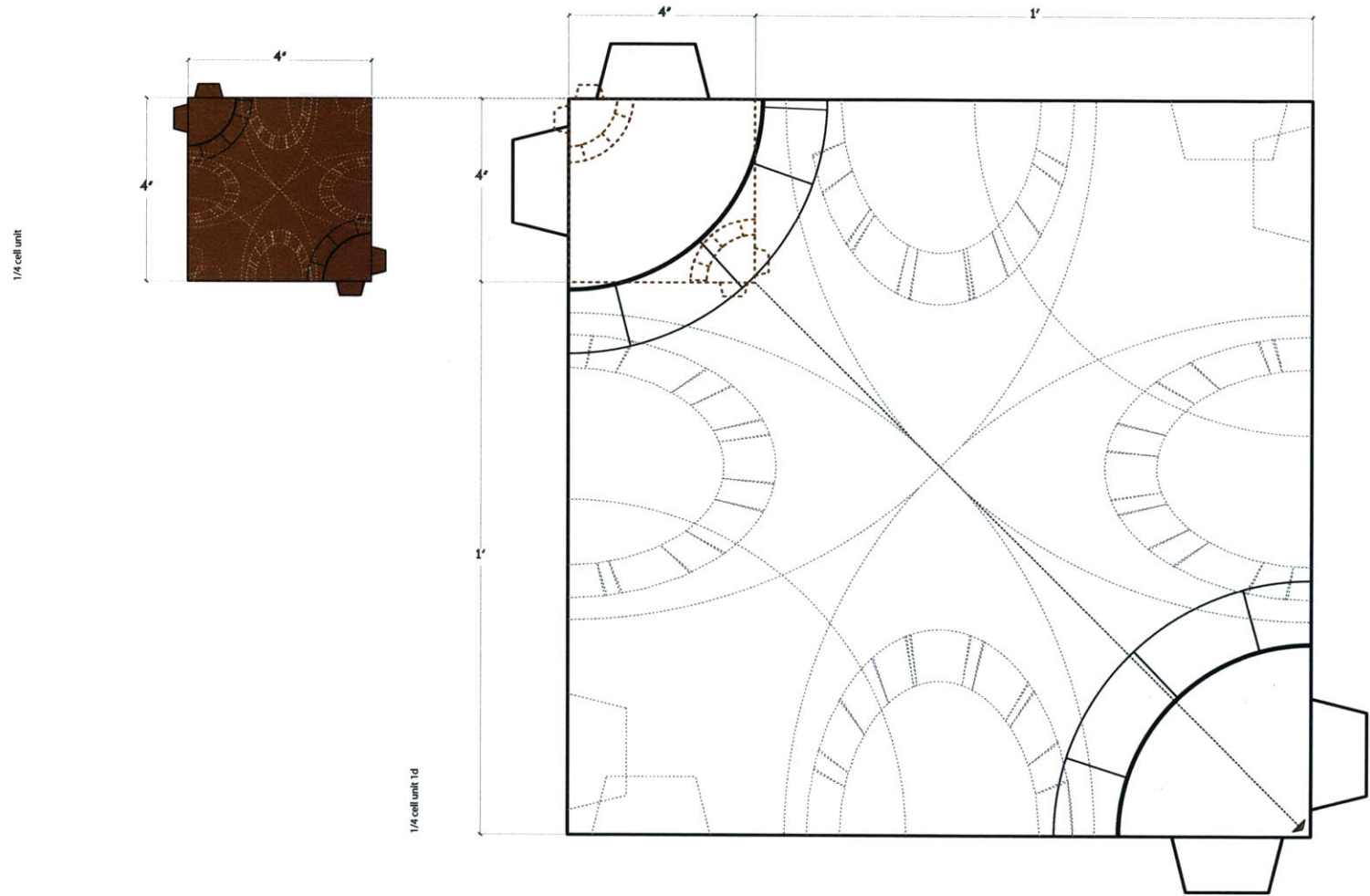
1/4 Cell Unit Variable Size Pours

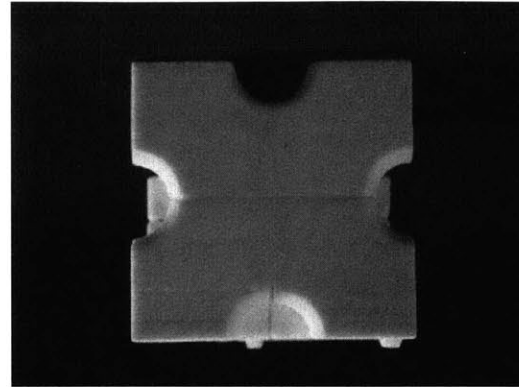
Through reconfigurable form work casting and unit aggregation, it is possible to create a larger wall surface with variable sized pours.



Cast Cell Unit 1

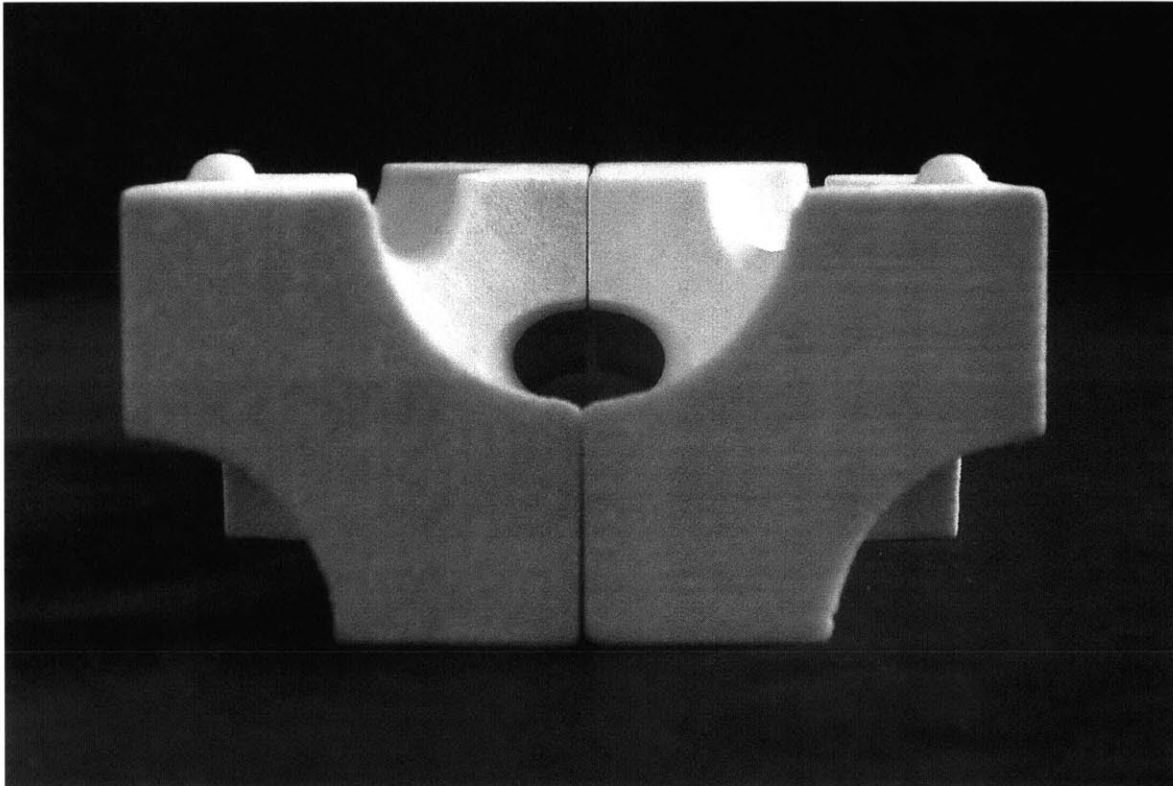
scaler transformation



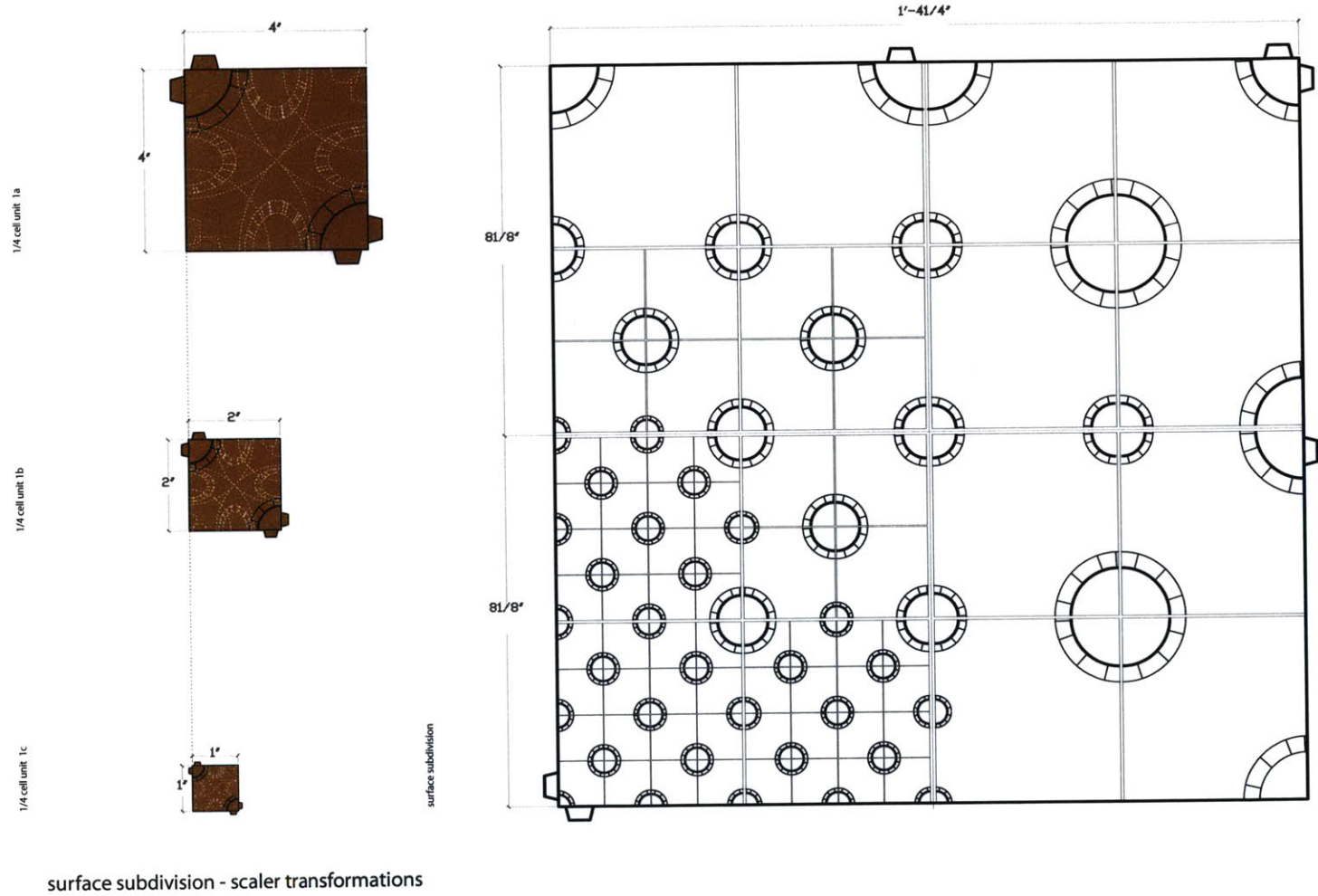


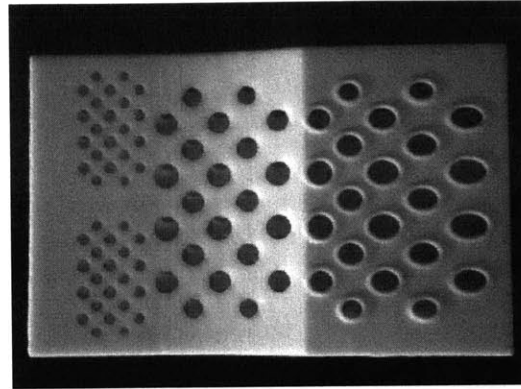
1/4 Cell Unit Scaler Shift

Scaler shifts can occur to accommodate structure.



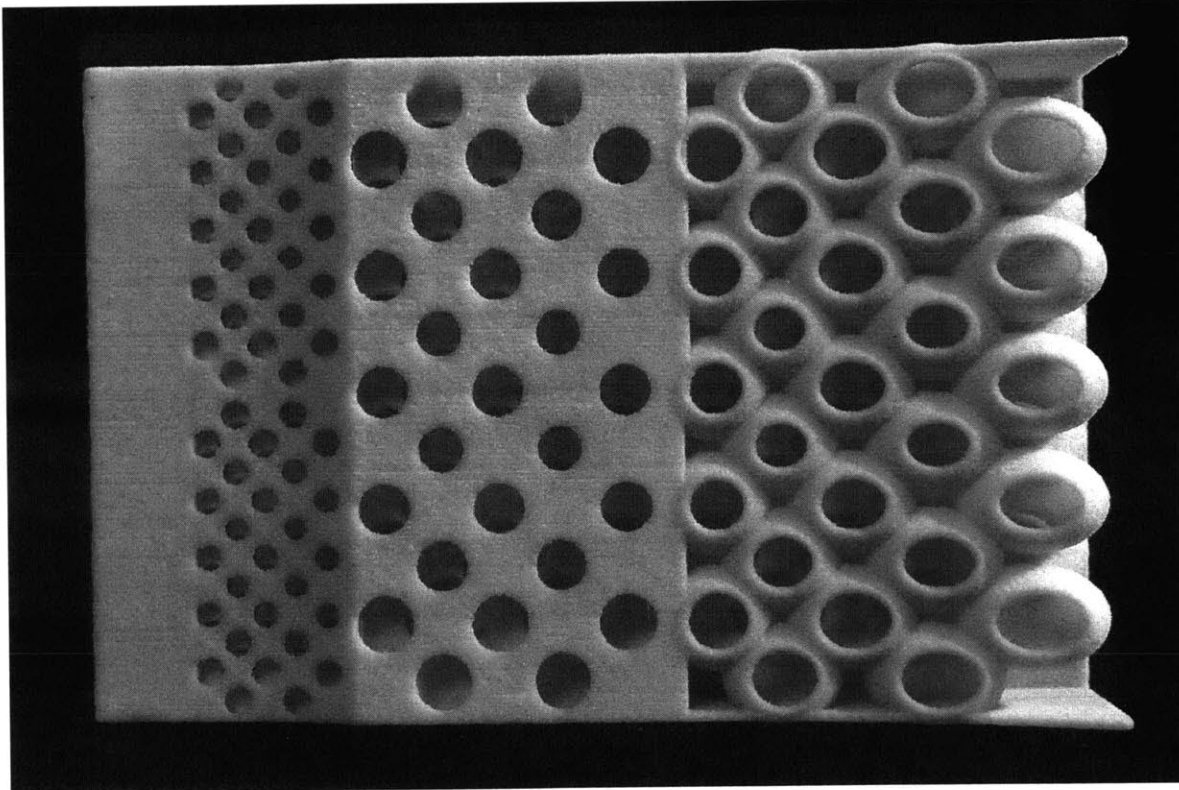
Cast Cell Unit 1



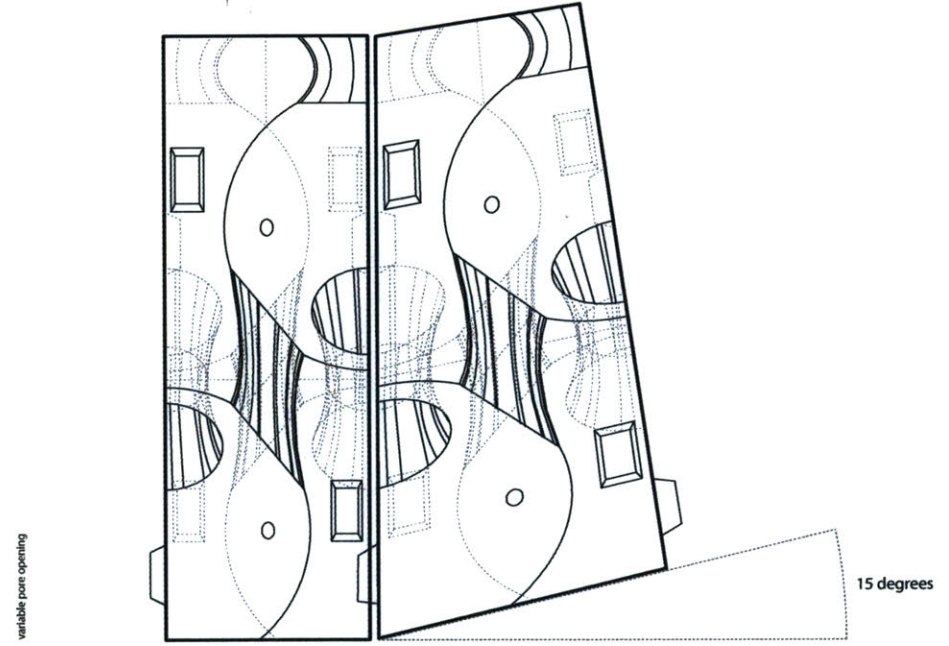
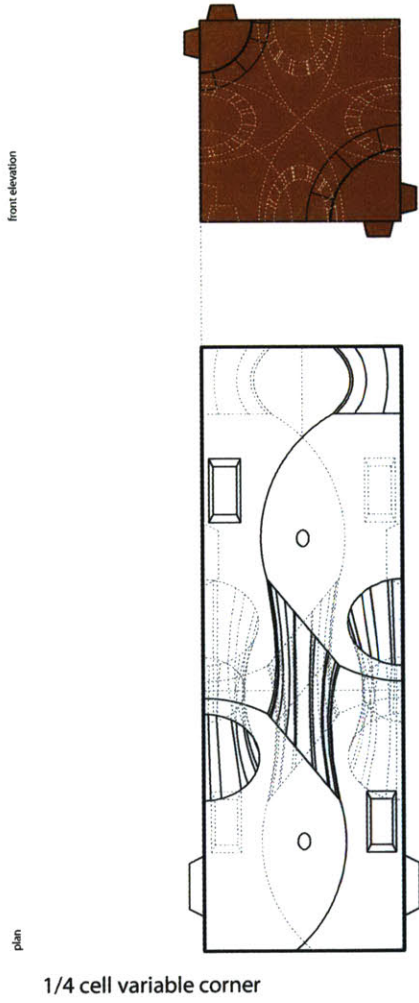


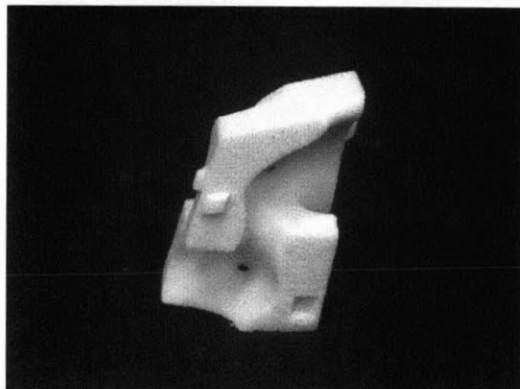
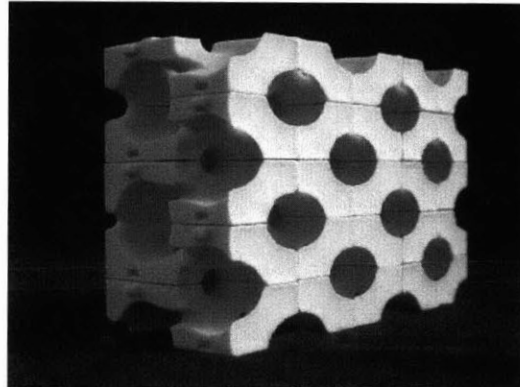
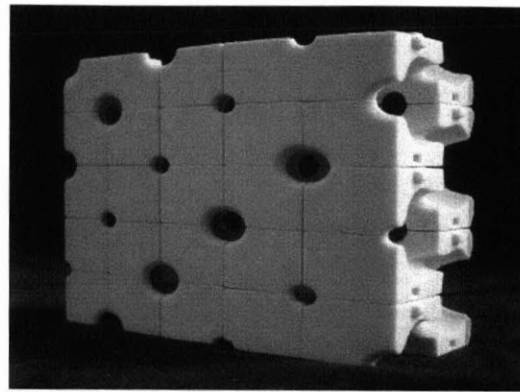
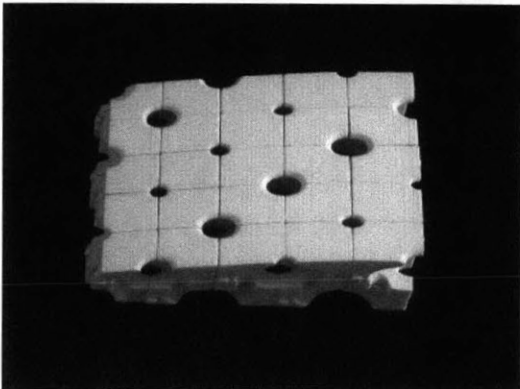
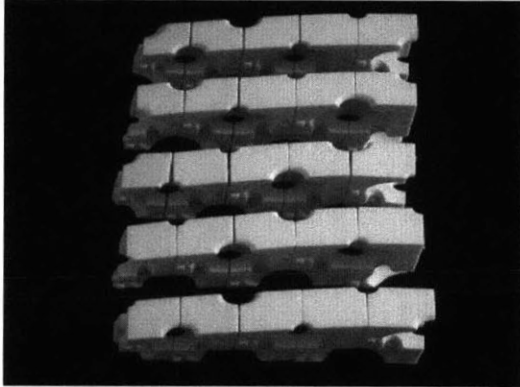
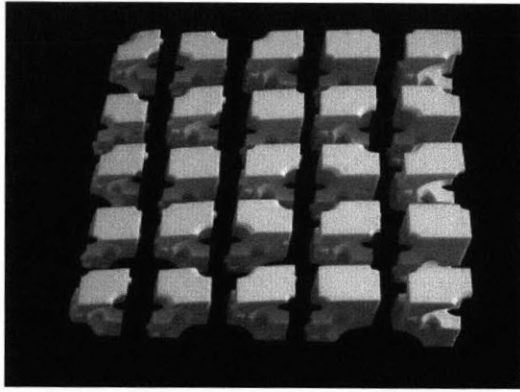
1/4 Cell Unit Scalar Subdivision

Various different scales can be brought together to create a variably scaled wall surface.



Cast Cell Unit 3



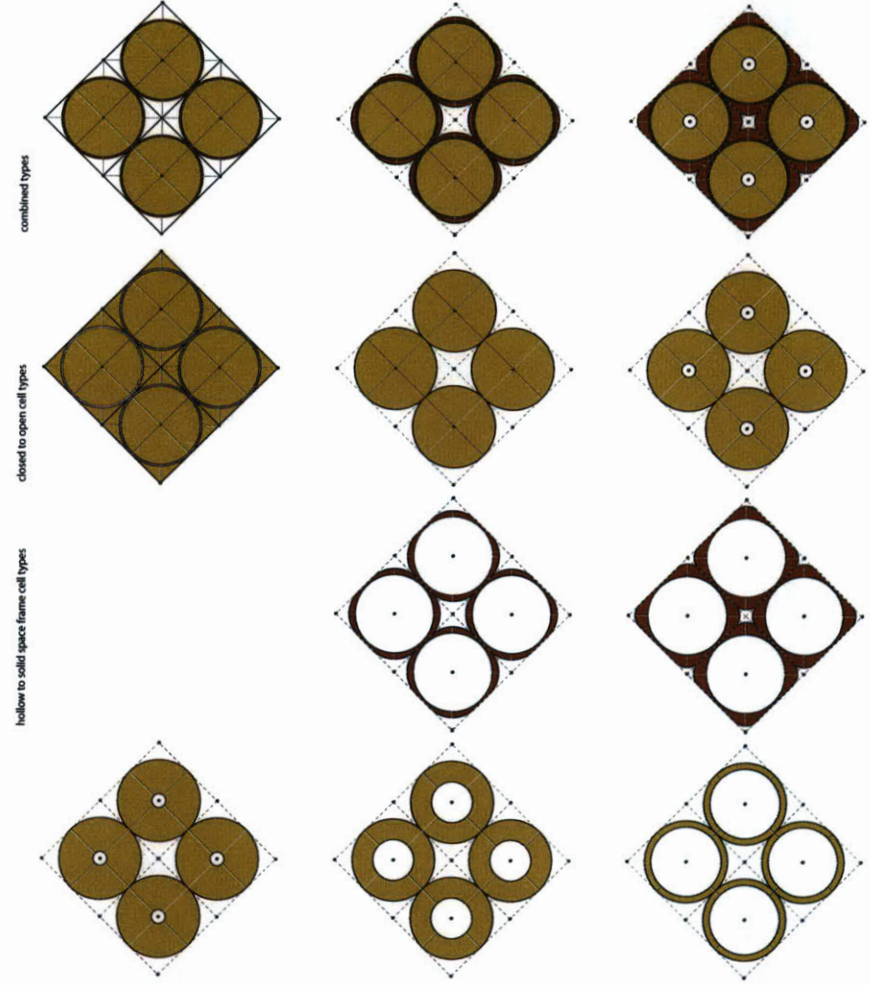
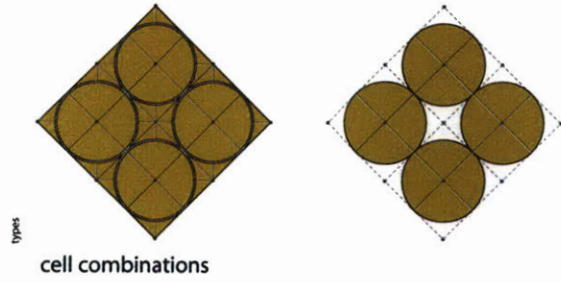


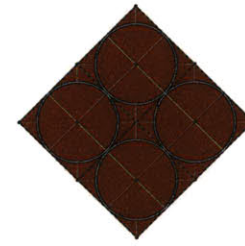
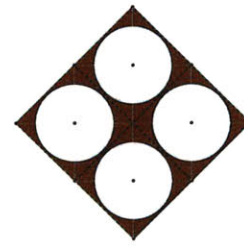
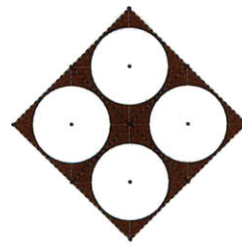
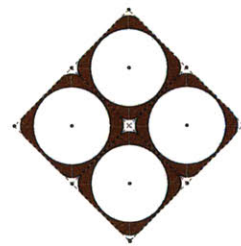
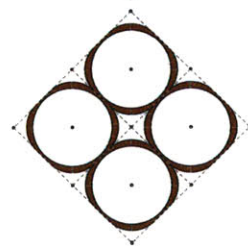
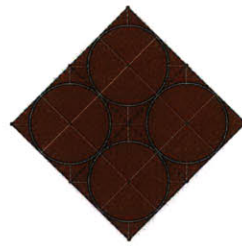
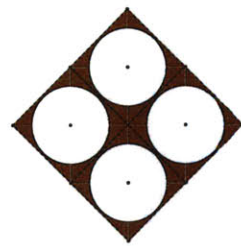
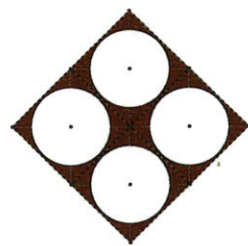
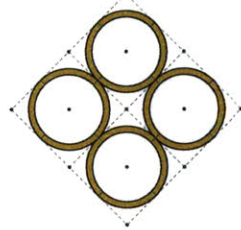
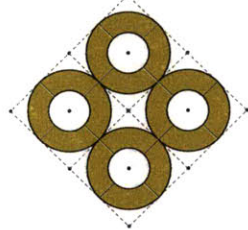
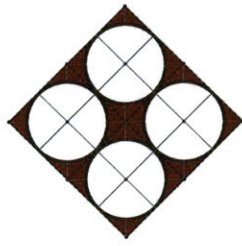
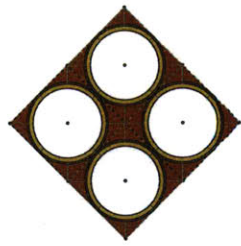
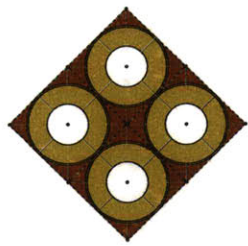
1/4 Cell Unit Deformations

Unlike the previous assemblies, this one demonstrates how the individual unit can deform slightly to create a larger variation in form.



Configuration Diagrams





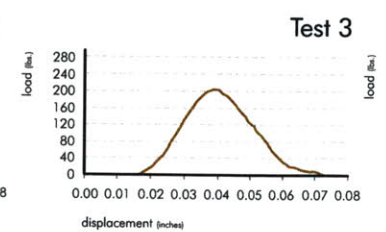
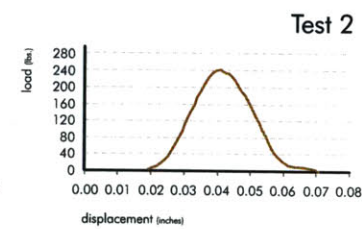
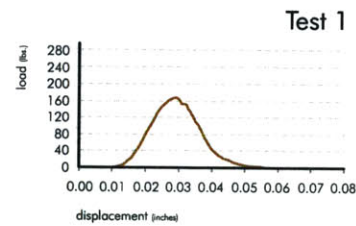
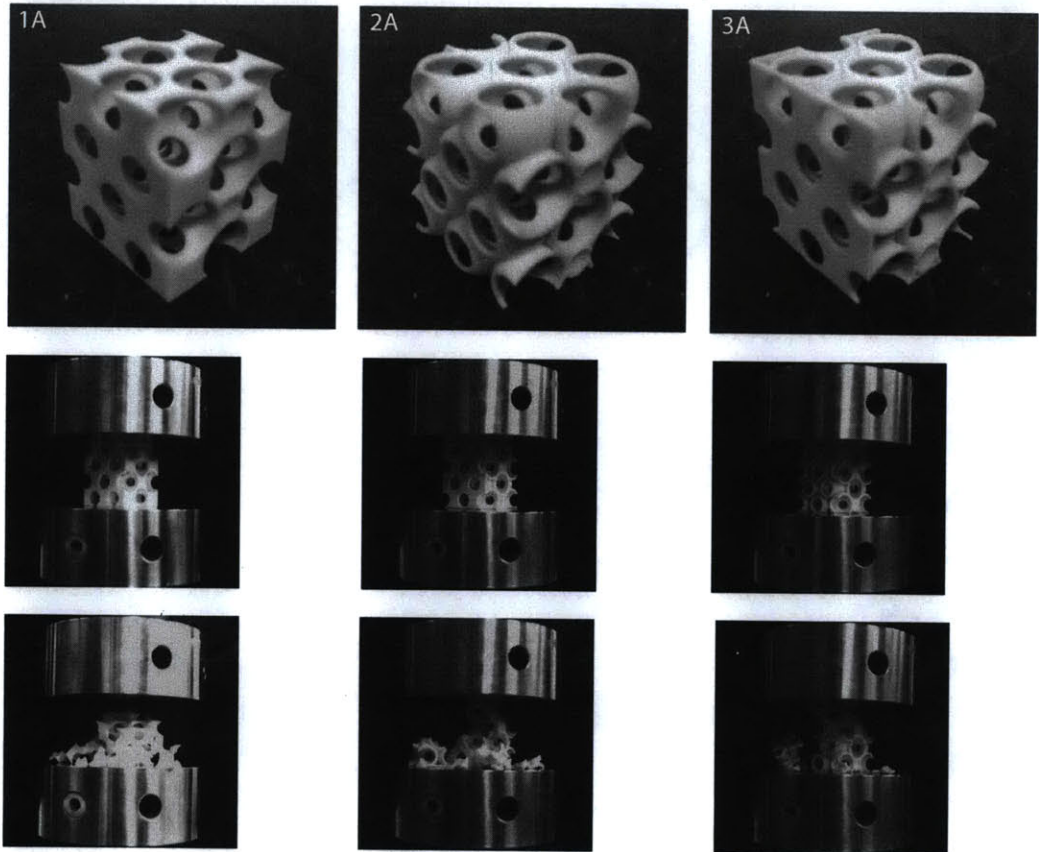
System Merging

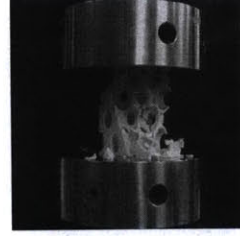
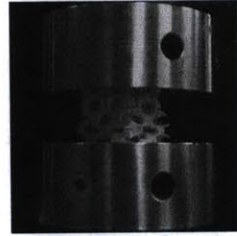
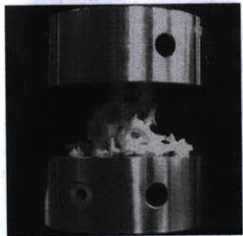
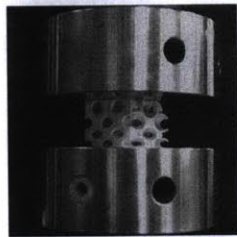
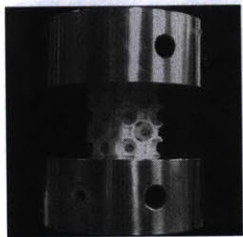
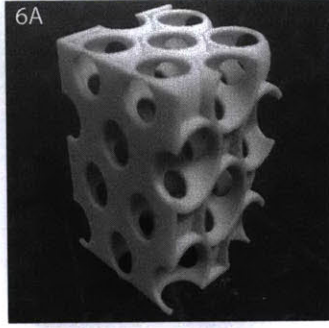
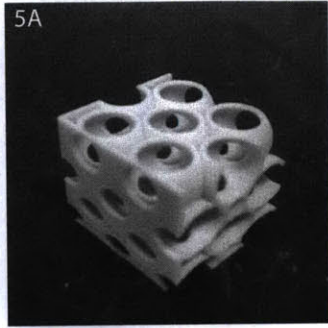
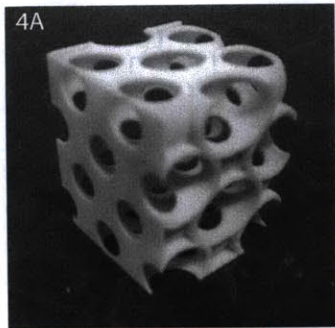
These diagrams and images illustrate how the two systems can come together to become one.

Structure Tests

These tests were conducted to verify some assumptions about the shapes of the cells. Specifically, if the cell begins to deform to take a parabolic shape, it should become stronger.

cell types

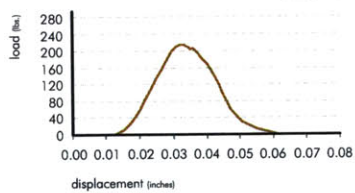




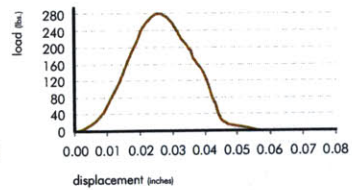
Test Results

The hypothesis was correct, configuration 6a was the strongest of the 6 models tested.

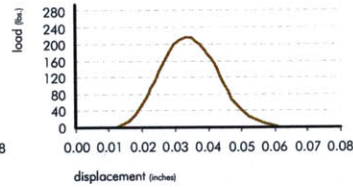
Test 4



Test 5

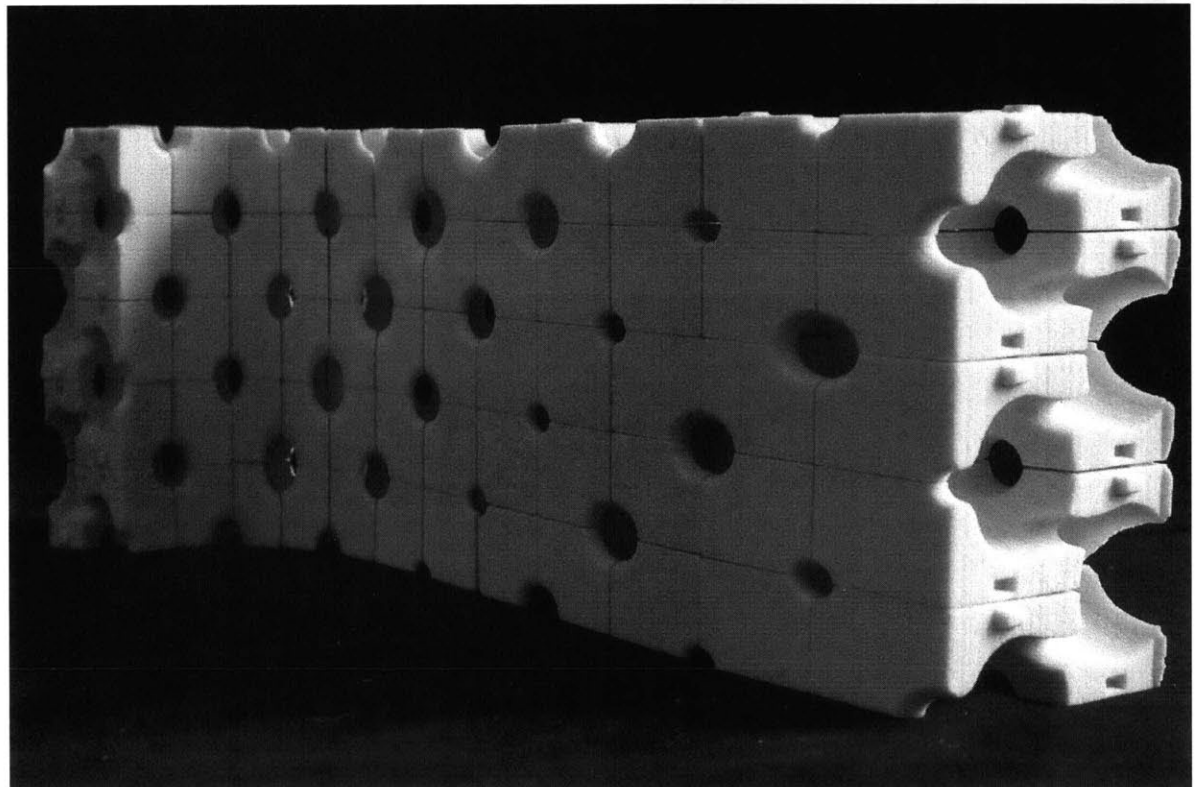
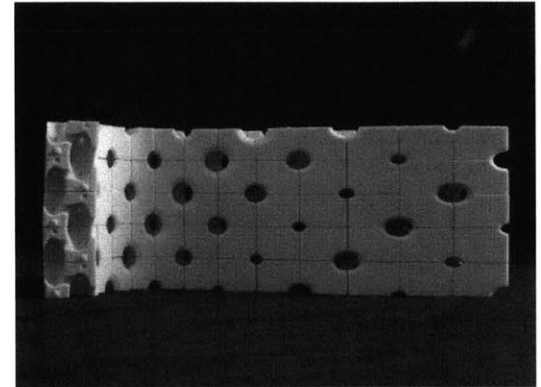
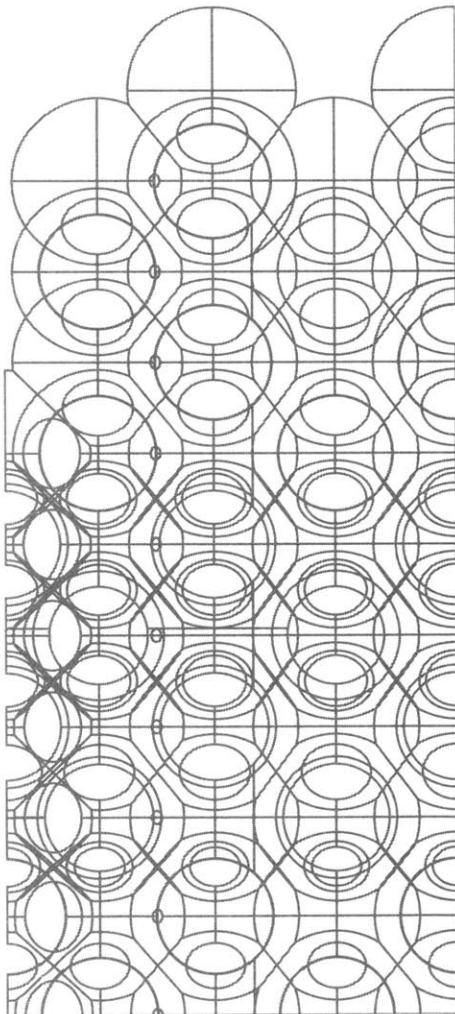


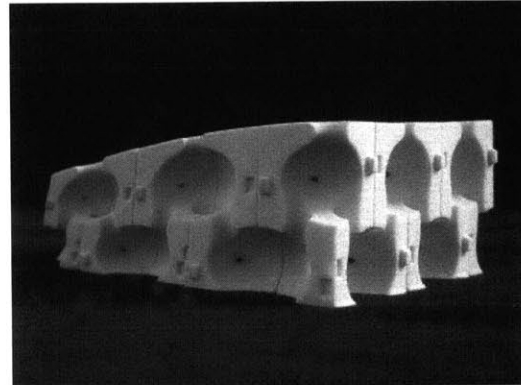
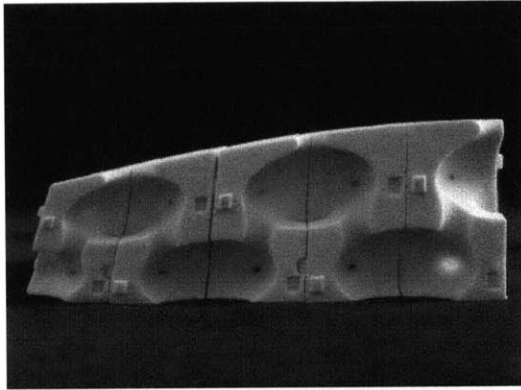
Test 6



aggregation studies

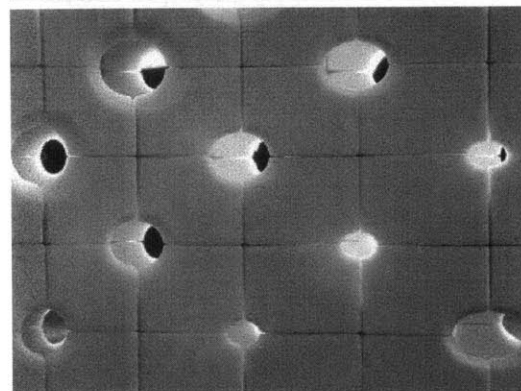
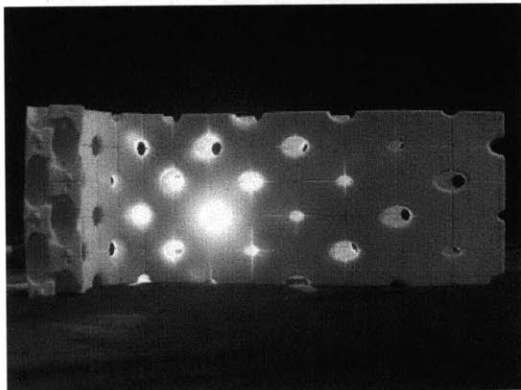
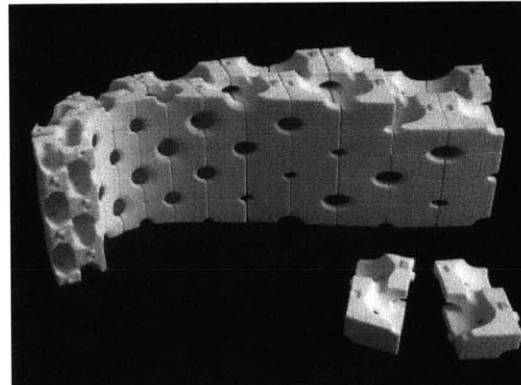
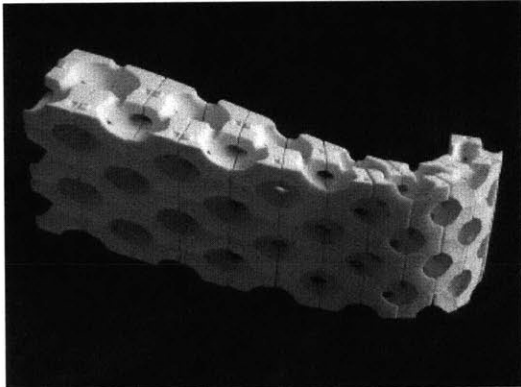
In the following exercises, the system needs to be transformed so as to incorporate a specific requirement.





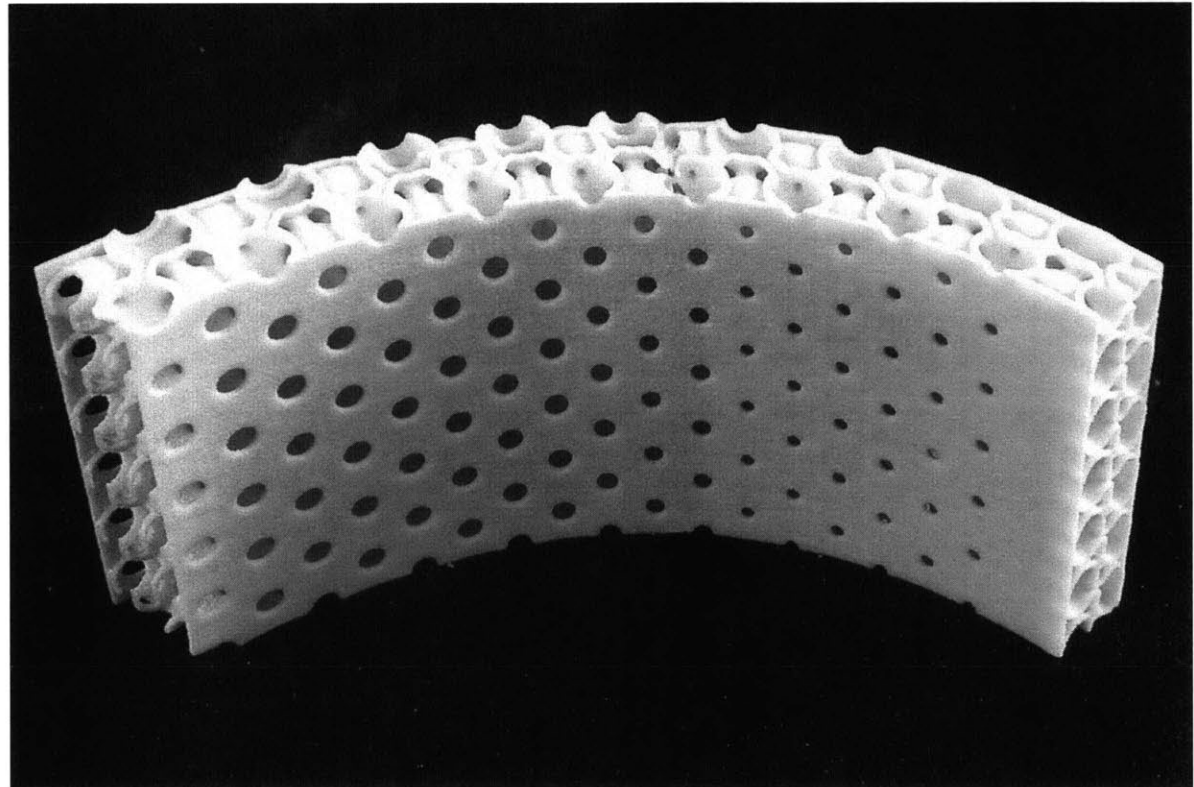
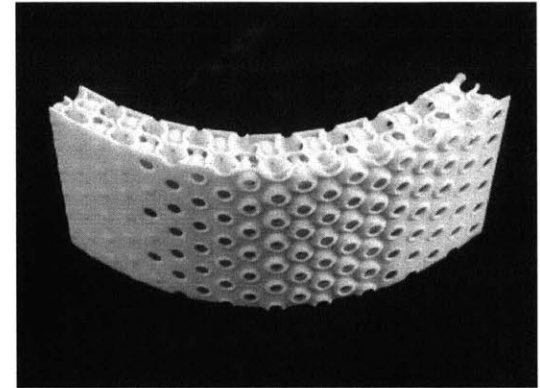
Exercise 5

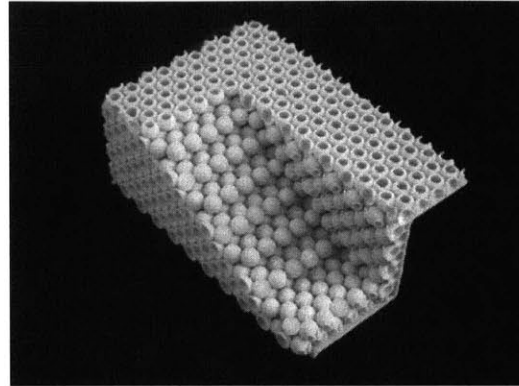
In this example the system must turn a corner, and vary in pours to filter light. The system must also thicken drastically in its depth.



Exercise 4

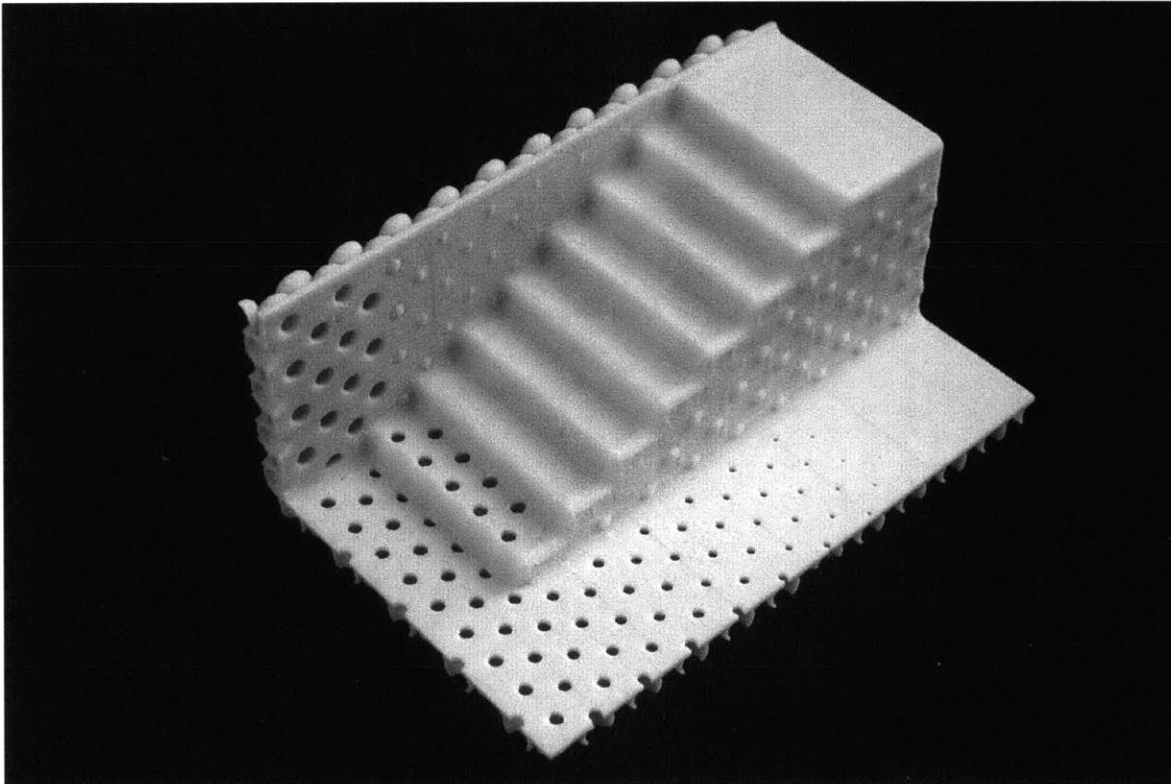
The system must gradually turn a corner while transitioning from impermeable to permeable. The cell shape must also deform to vary the walls thickness slightly.





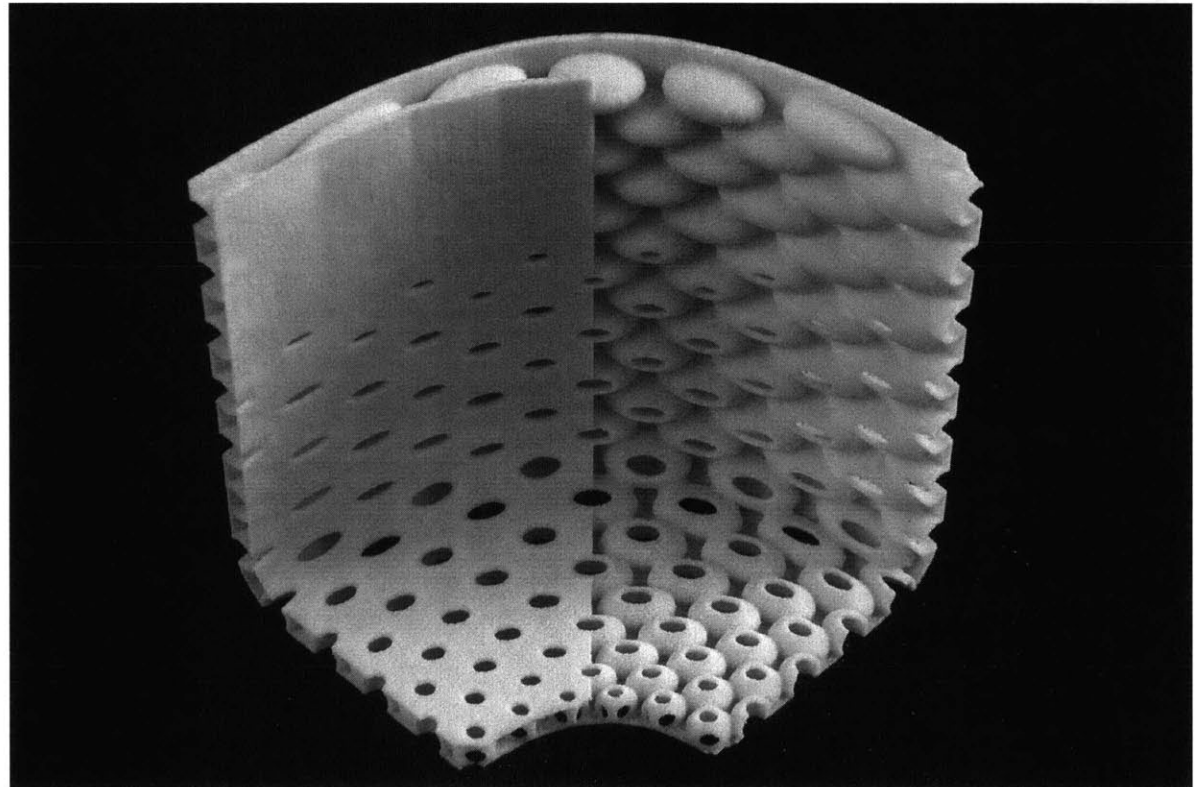
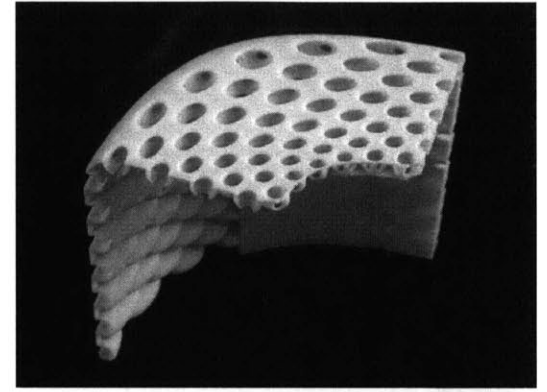
Exercise 3

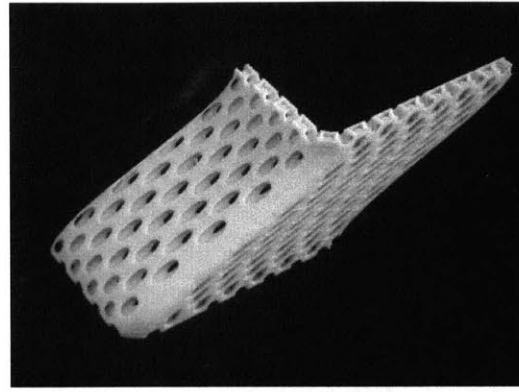
The system must aggregate to form a stair while maintaining the same shape and scale of unit.



Exercise 2

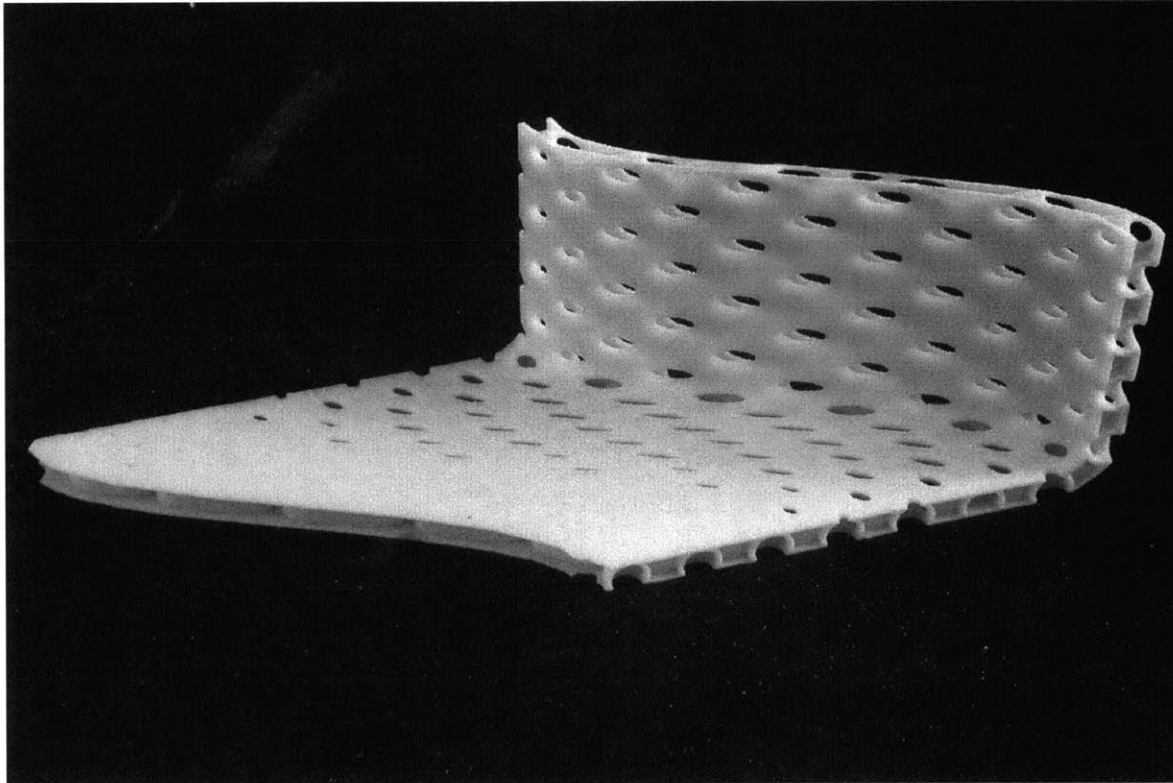
The system must turn 3 axis. One edge must turn gradually while the other turns quickly.



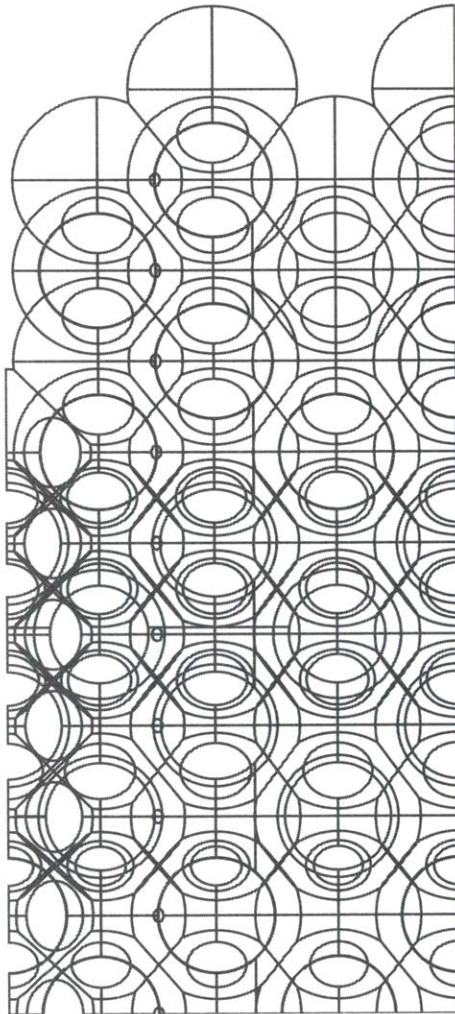


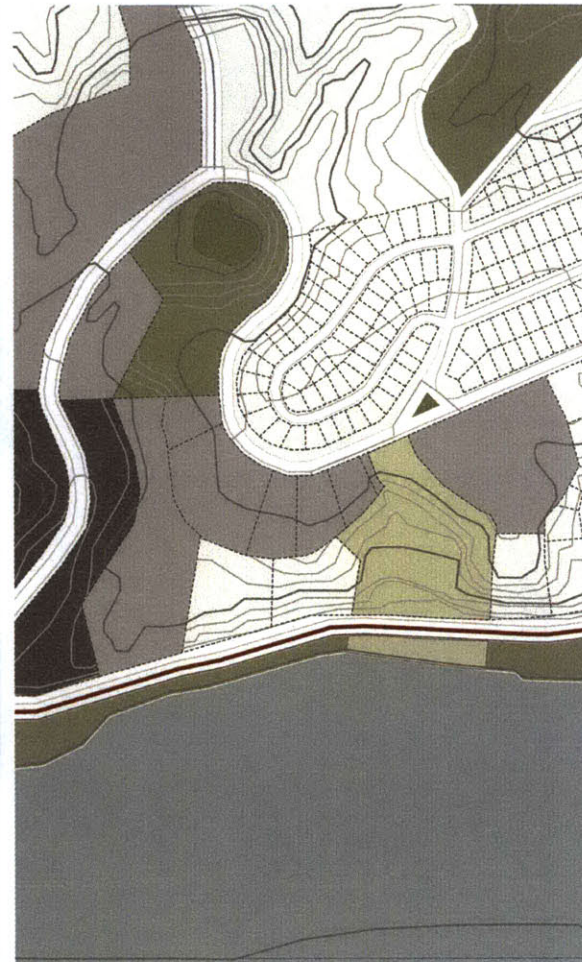
Exercise 1

The system must turn a corner and deform the cells to create directionality.

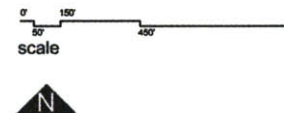


site



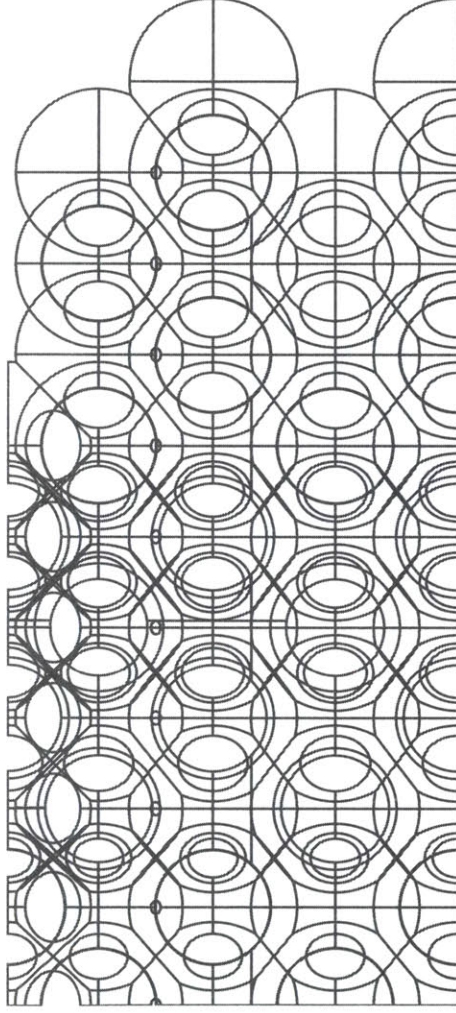


site
 public parks
 low density housing
 mid density housing
 commercial
 ocean



Situated between Malibu and Santa Monica, the mountainous site has an amazing view of the pacific ocean. The aim of this site intervention is to make better use of the Santa Monica Mountain cliffside. The cellular system I have developed will be used to become the following:

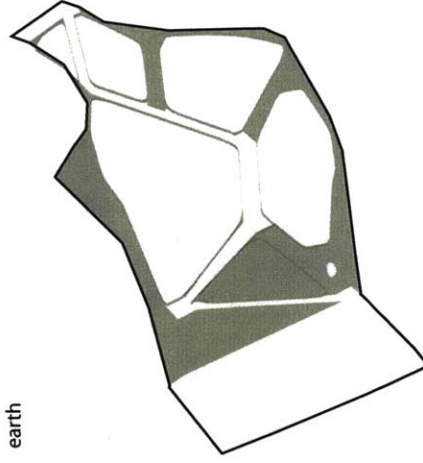
Road Paver
 Retaining Wall
 Beach Boardwalk
 Sound Barrier
 Open Air Enclosure
 Bridge Structure



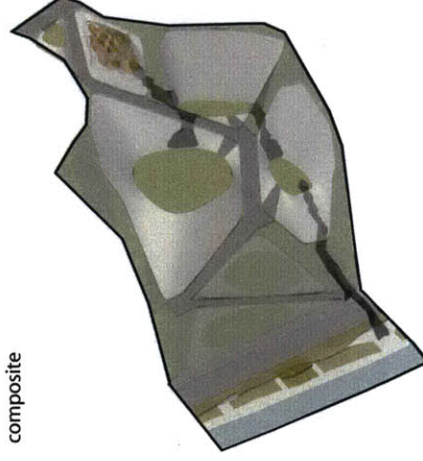
intervention

Programmatic diagrams

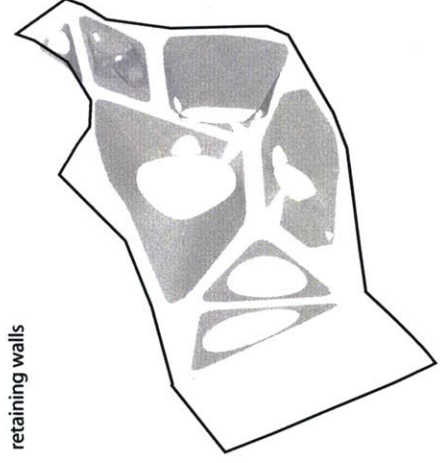
earth



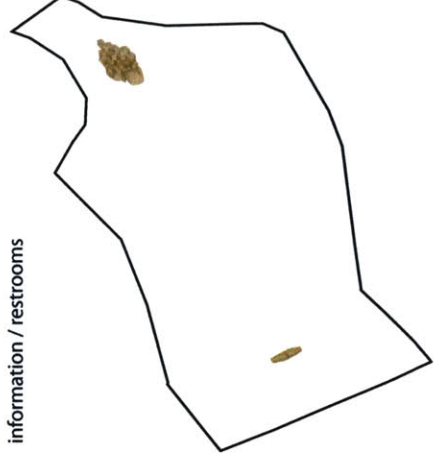
composite



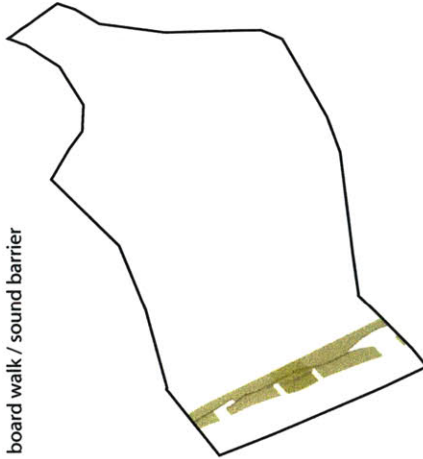
retaining walls



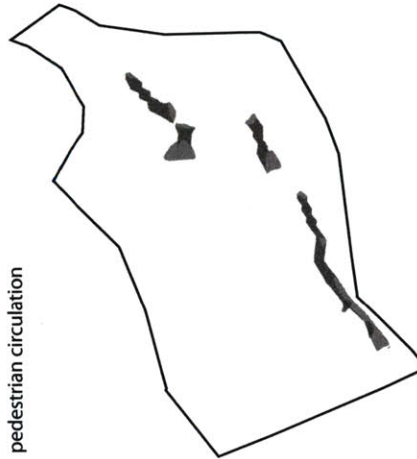
information / restrooms



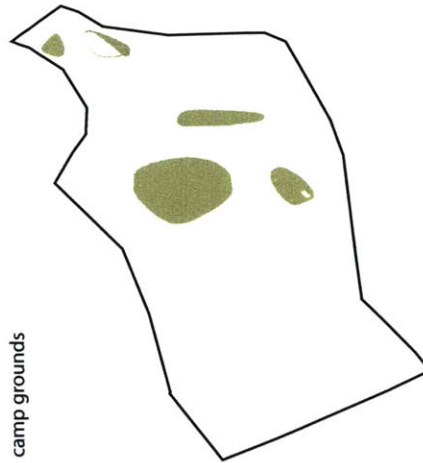
board walk / sound barrier



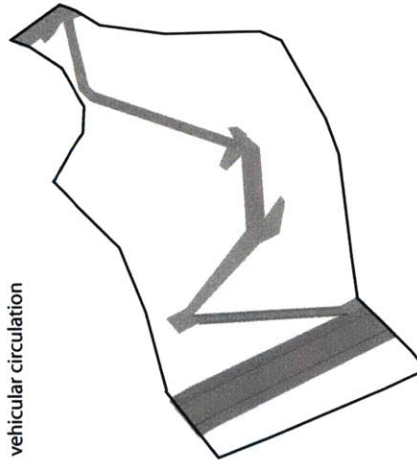
pedestrian circulation



camp grounds

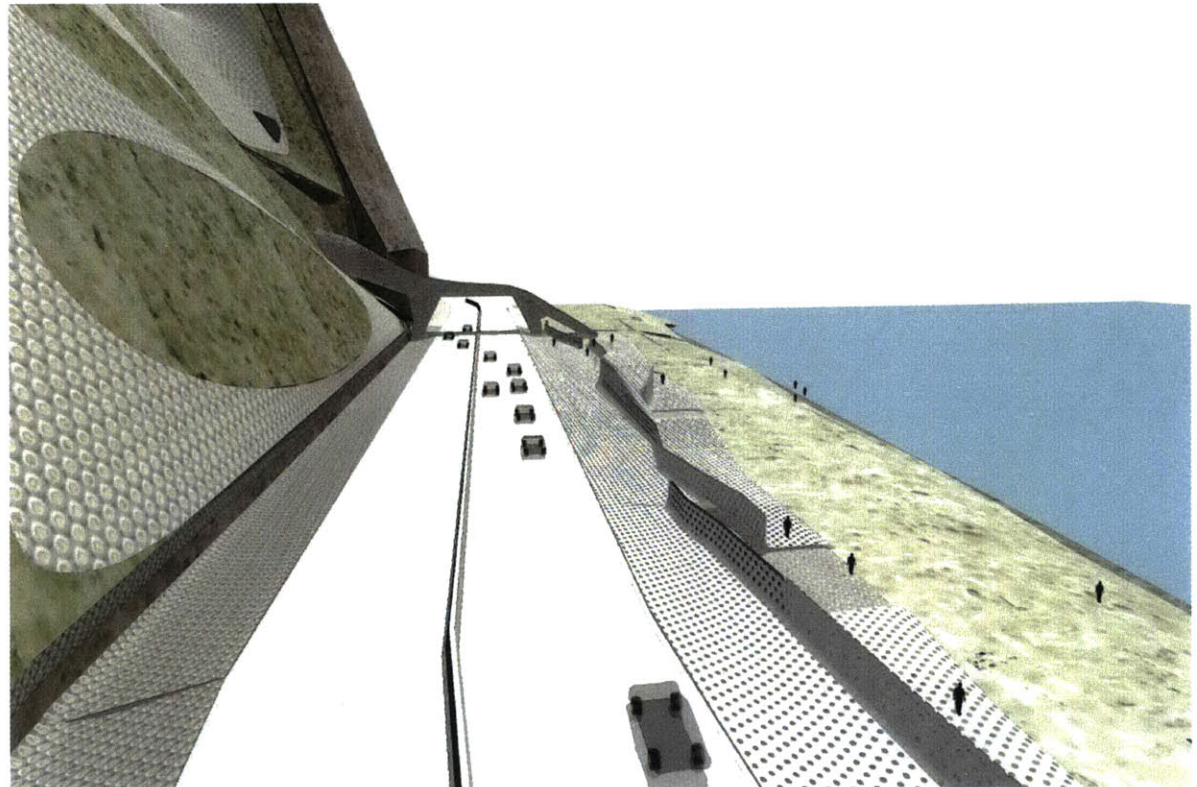
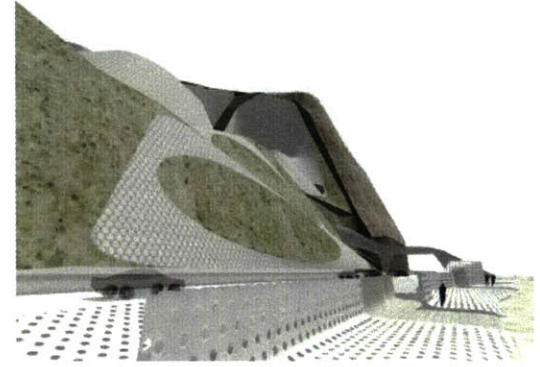
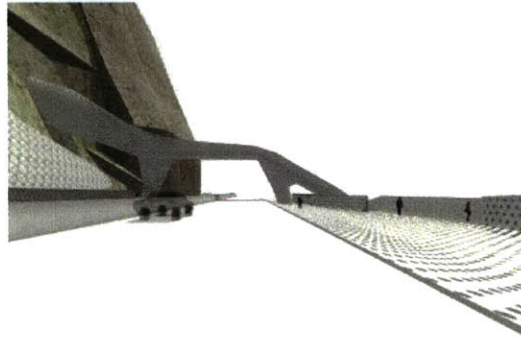


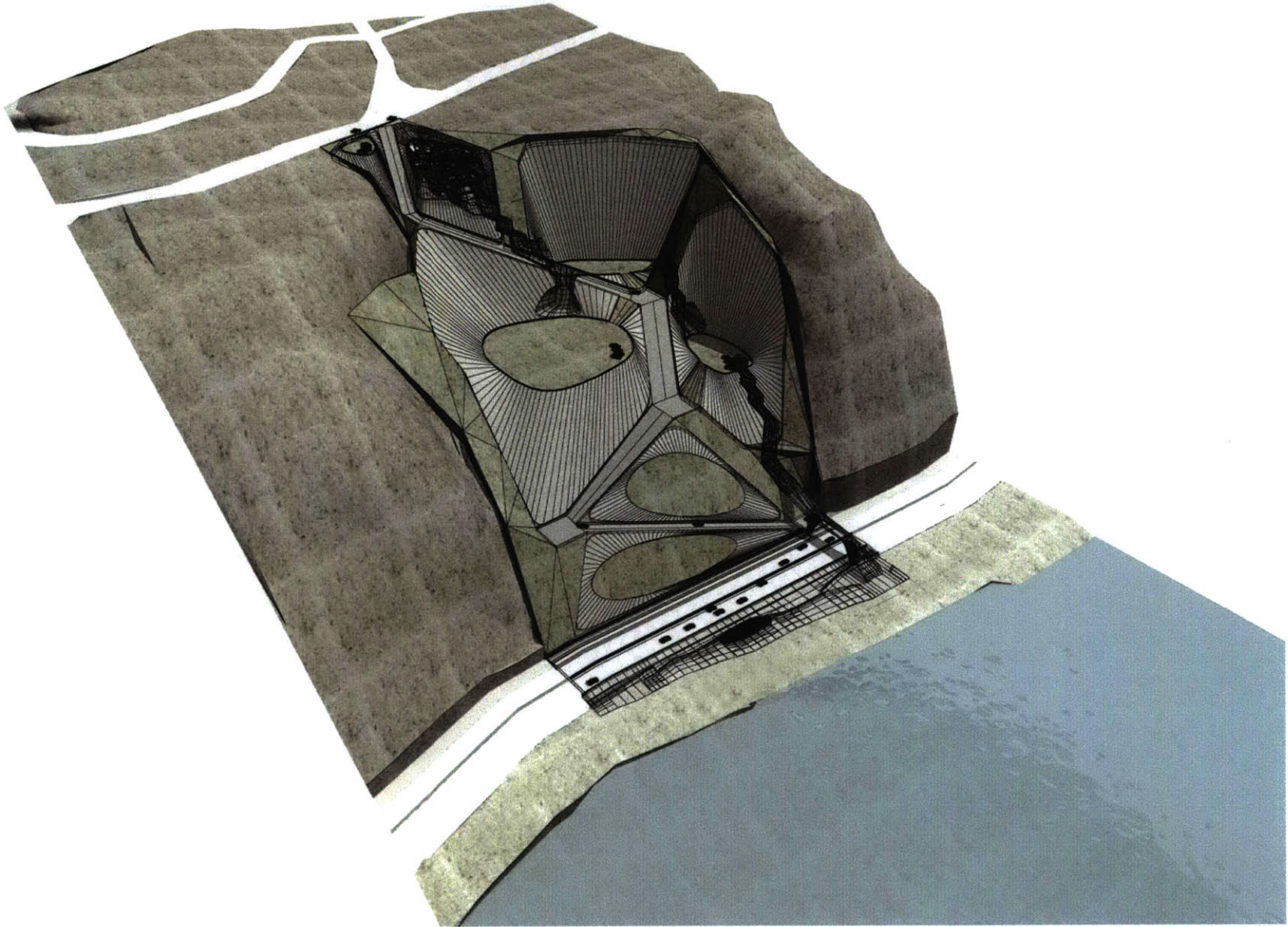
vehicular circulation



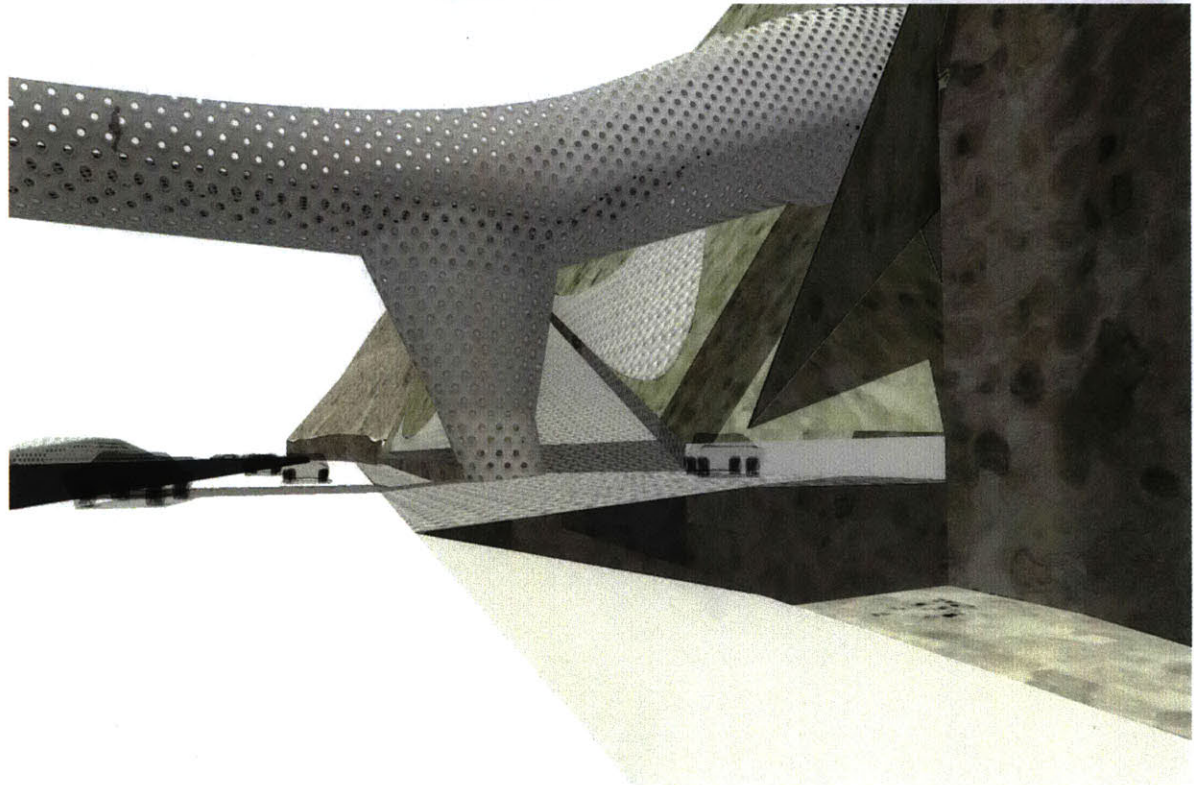
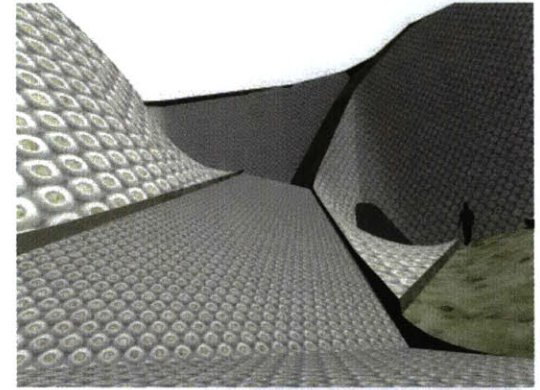
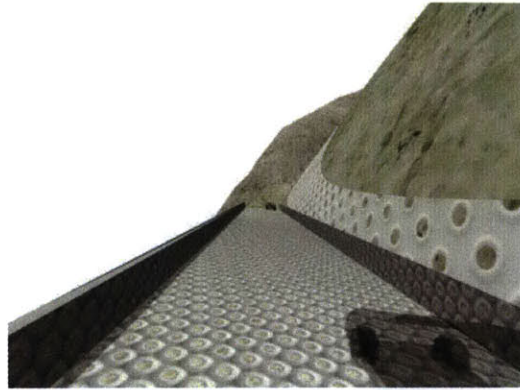
By employing the selectively permeable cellular building system, this thesis seeks to create a fusion between building and landscape. The idea is to forge unexpected programmatic and formal combinations by fusing material and context. Furthermore, the aspirations of this project will be to create an architecture of transition and filtration where experiences of spatial sequence, procession, contrast, tactility, and sectional difference are defined by and employed within and between a series of camp grounds set of the coast Santa Monica on the Topanga Canyon landscape. The spatial quality of the enclosed visitors space is regulated by the unique configuration of the cellular enclosure system.

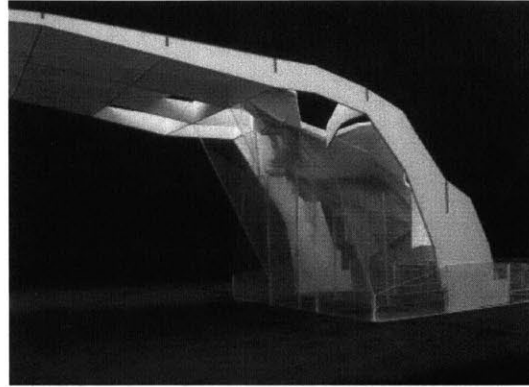
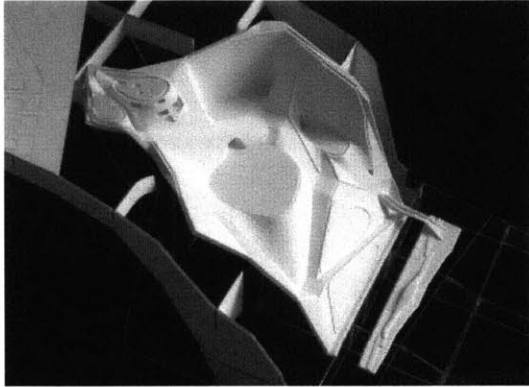
Views from Pacific Highway



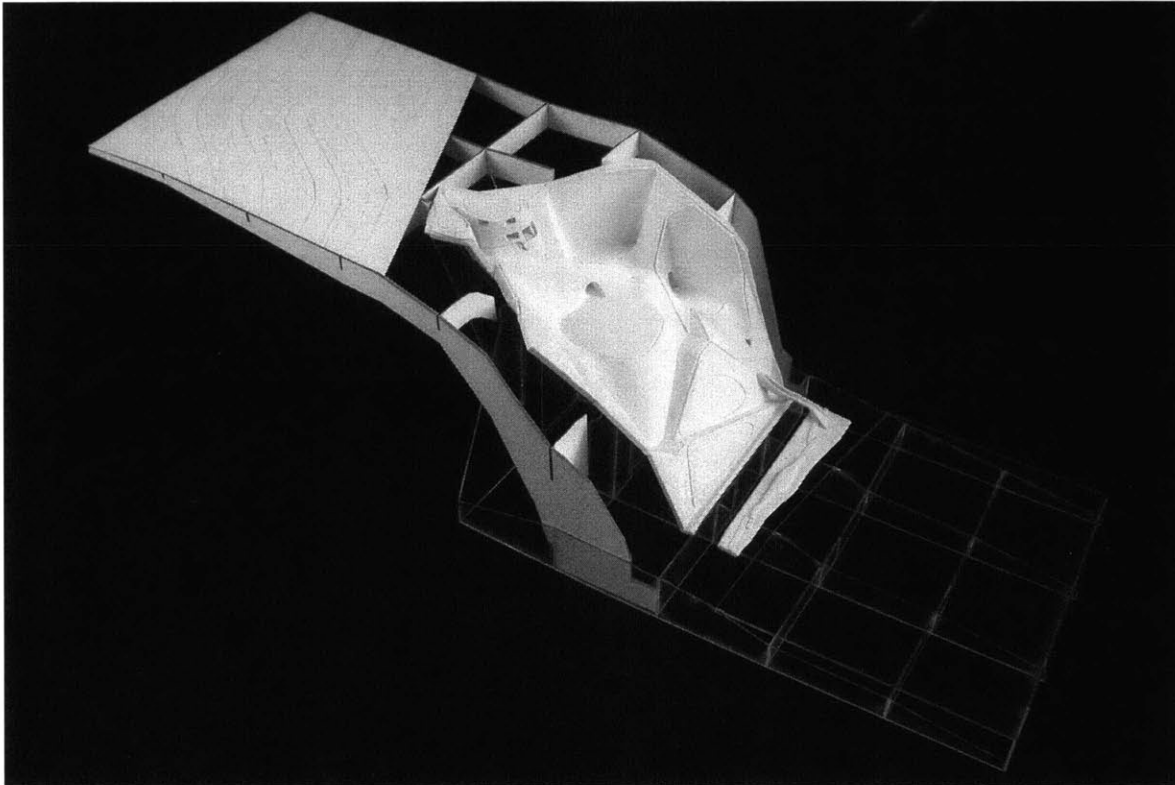


Views Entering the Site

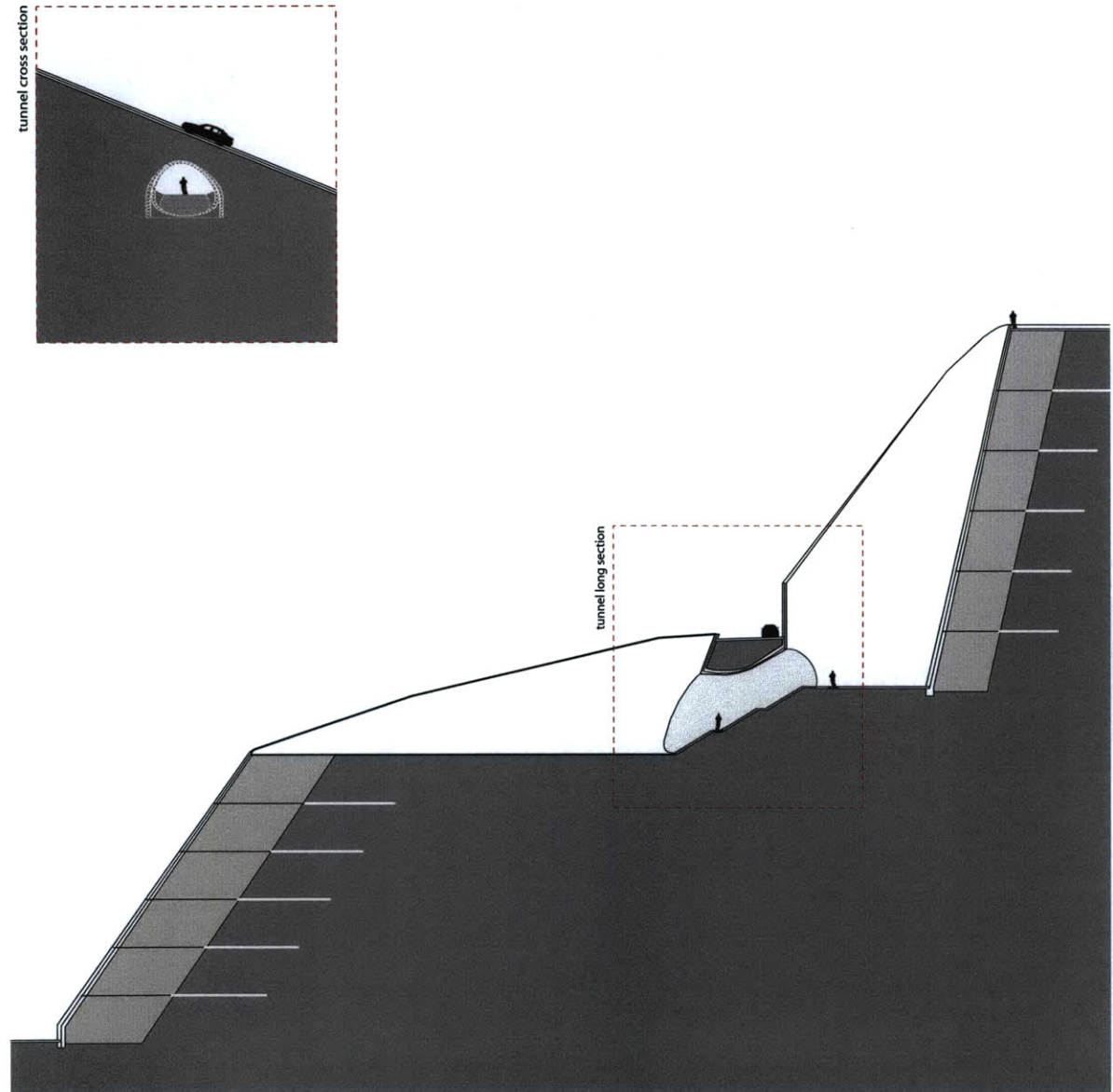




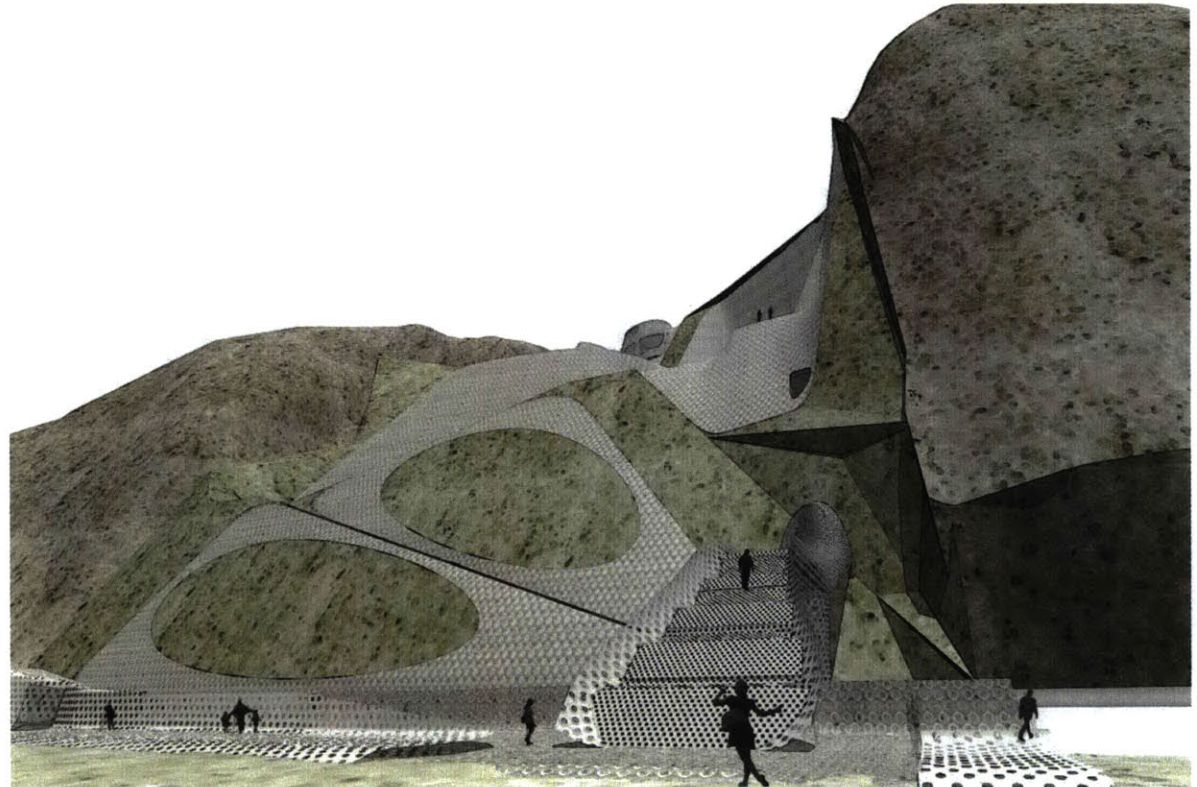
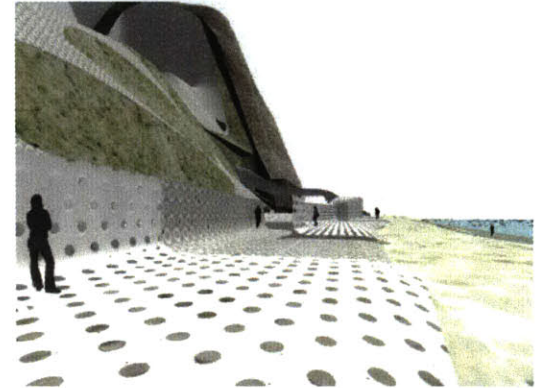
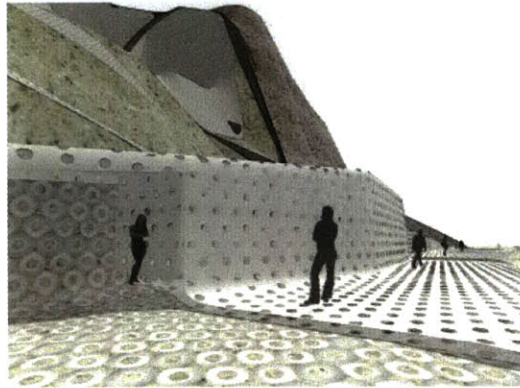
Conceptual Site Model

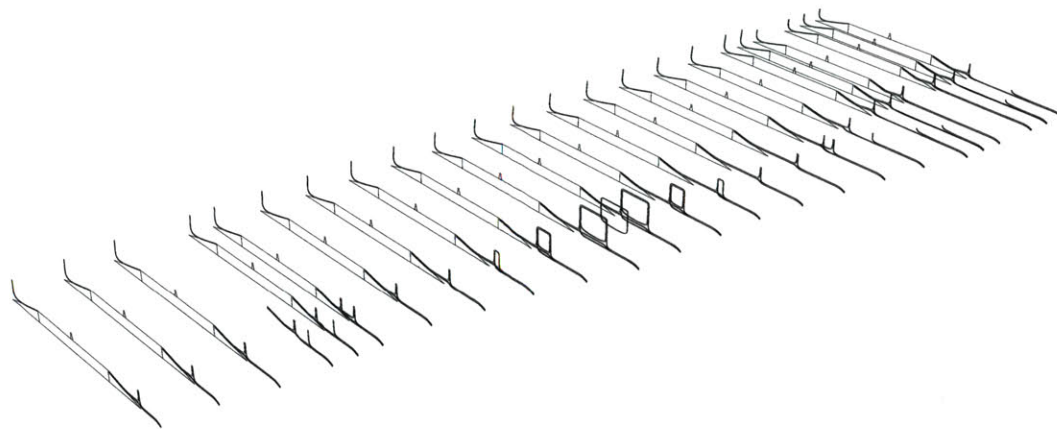


Retaining Wall Cross Section

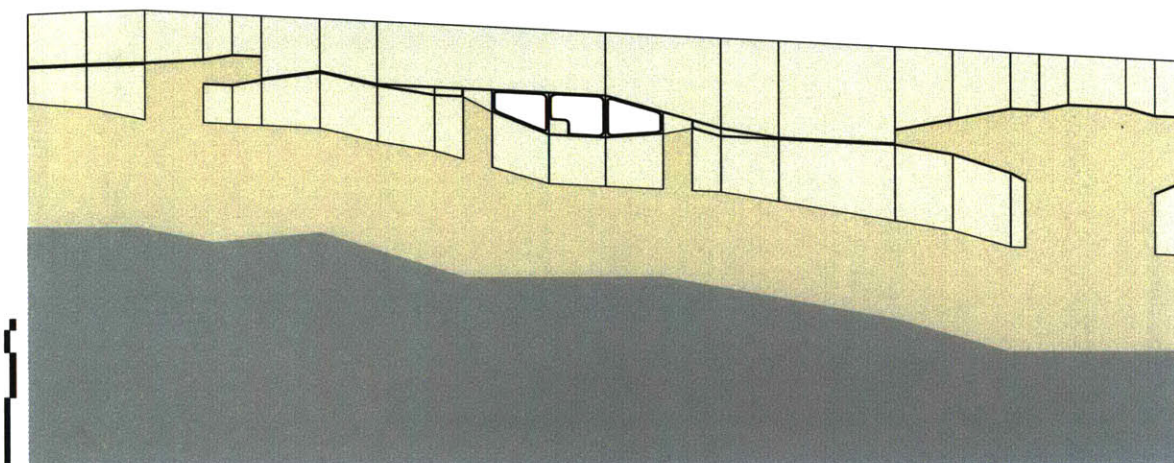


View of Board Walk/Sound Barrier

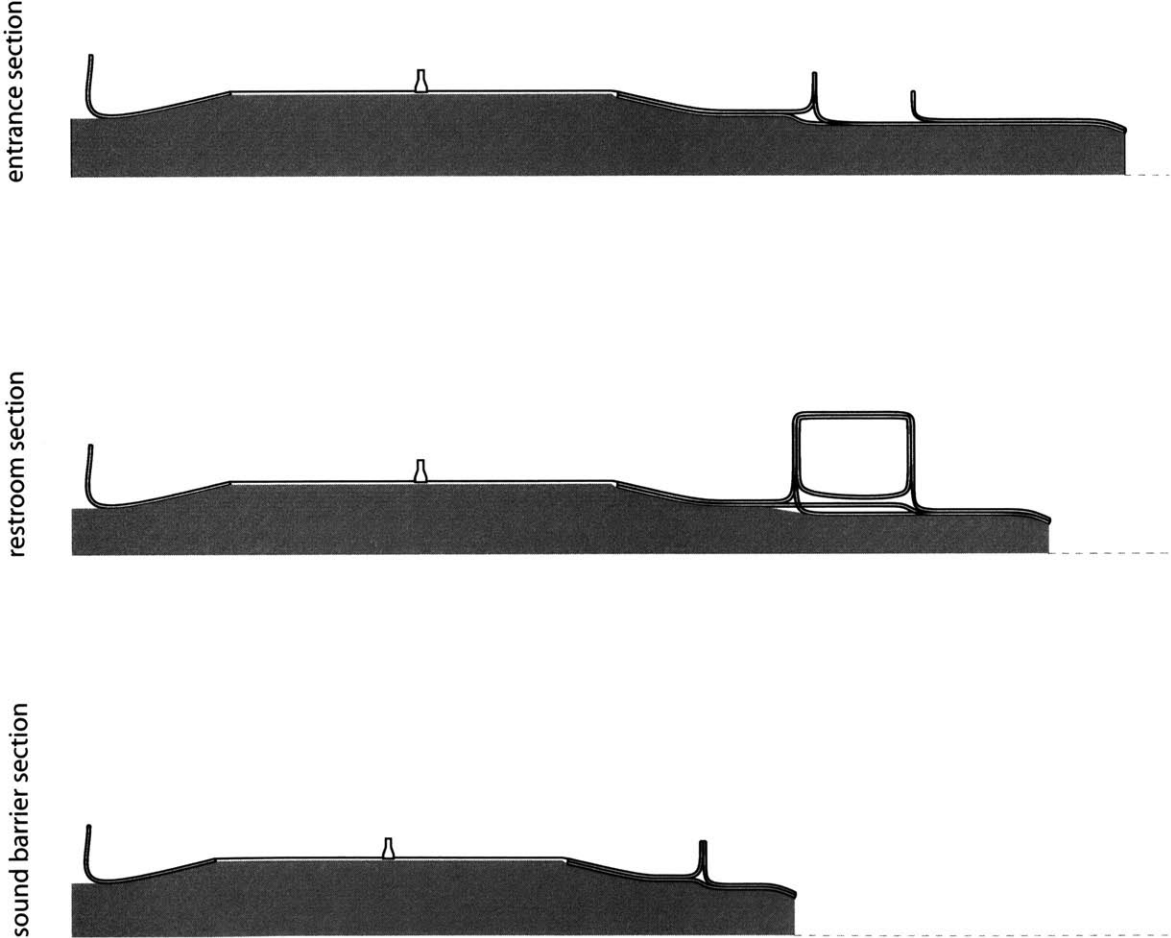


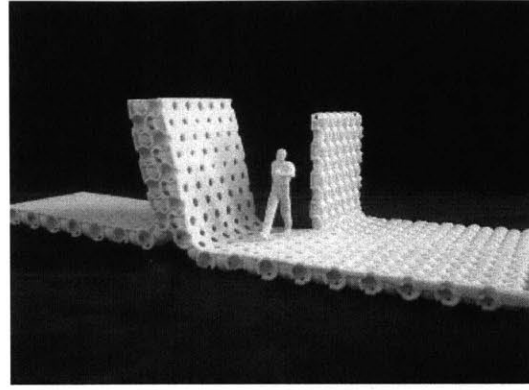
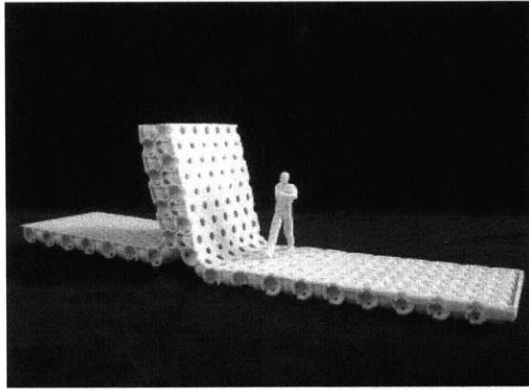


Board Walk/Sound Barrier Diagram

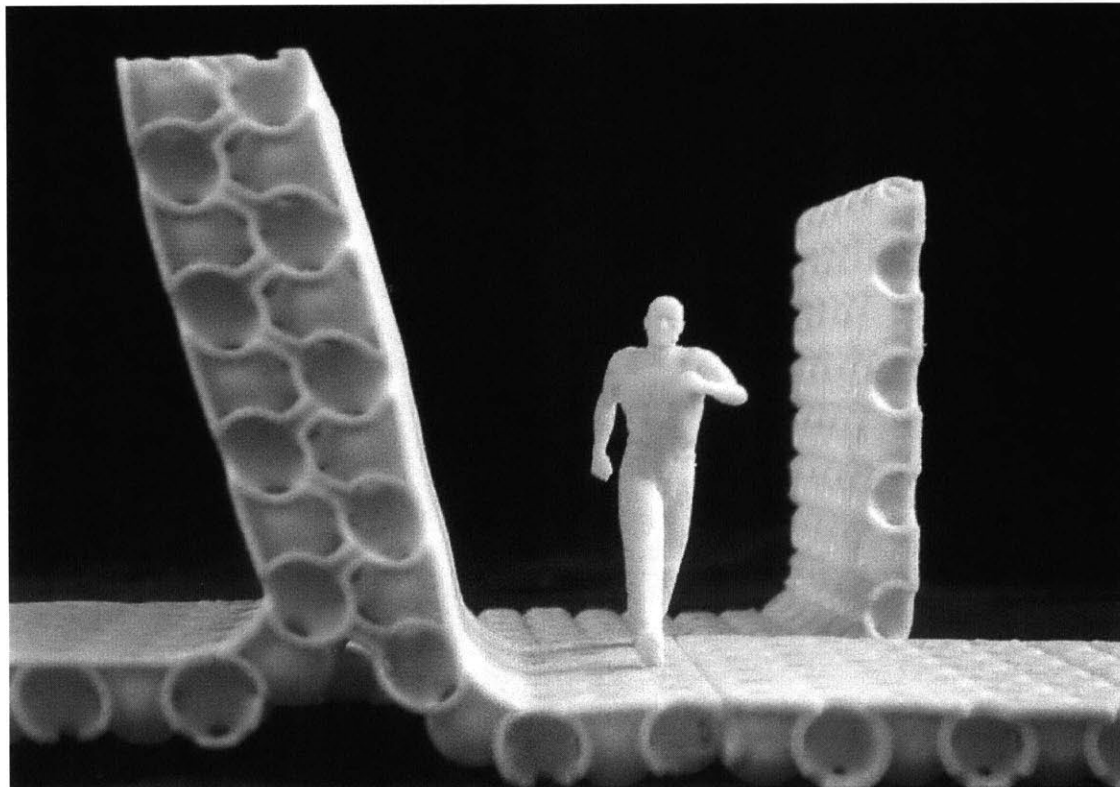


Board Walk/Sound Barrier Sections

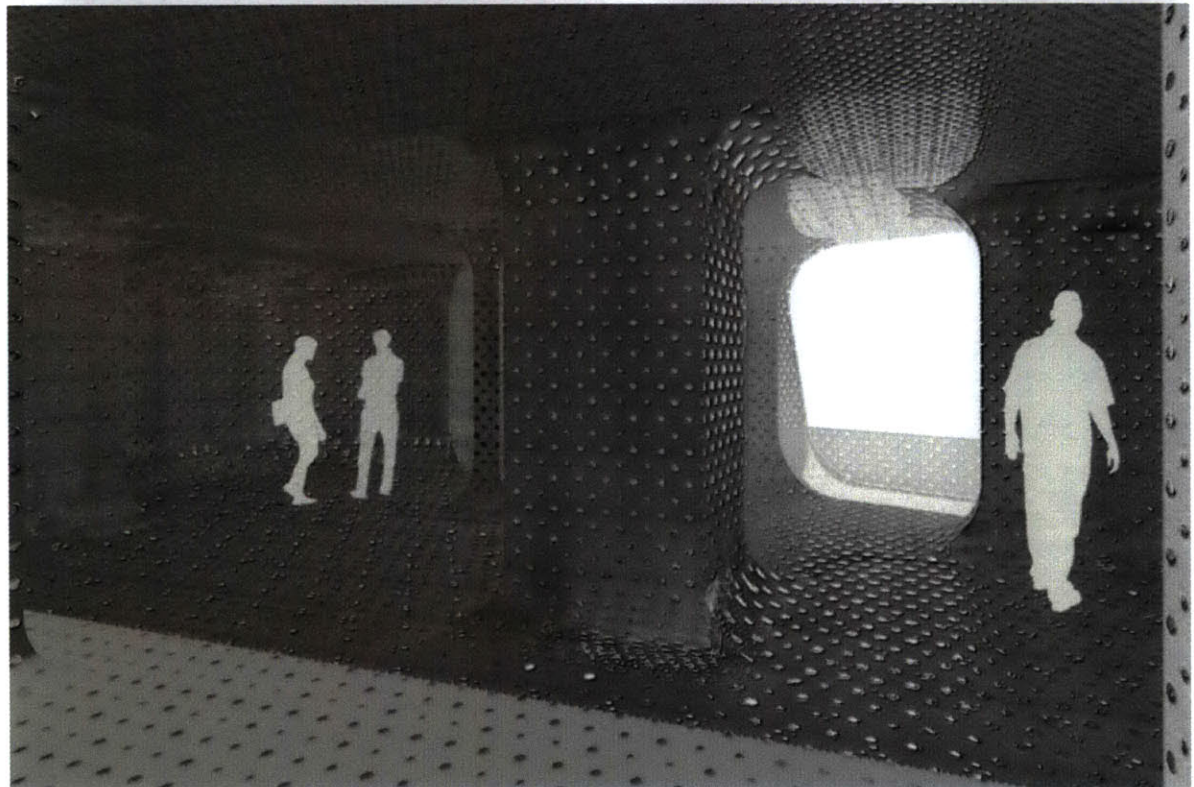
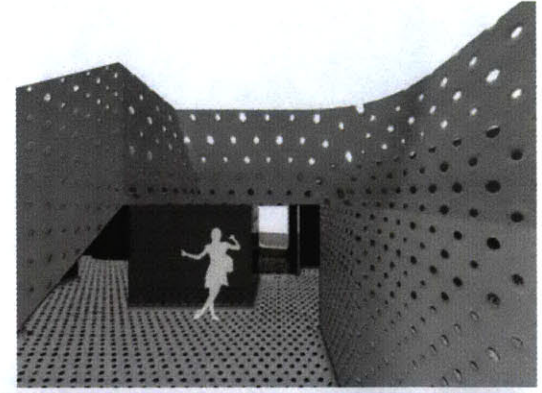
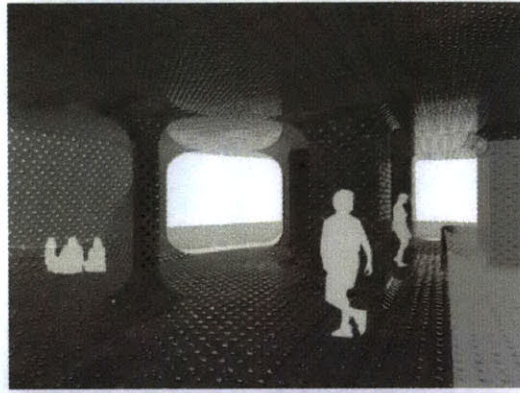


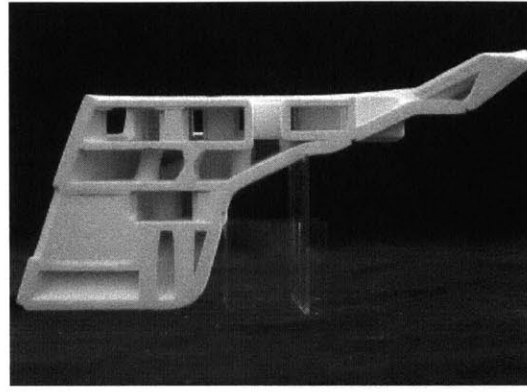
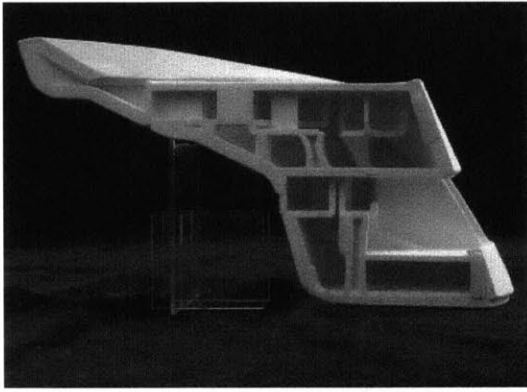


Board Walk/Sound Barrier
Detail Model

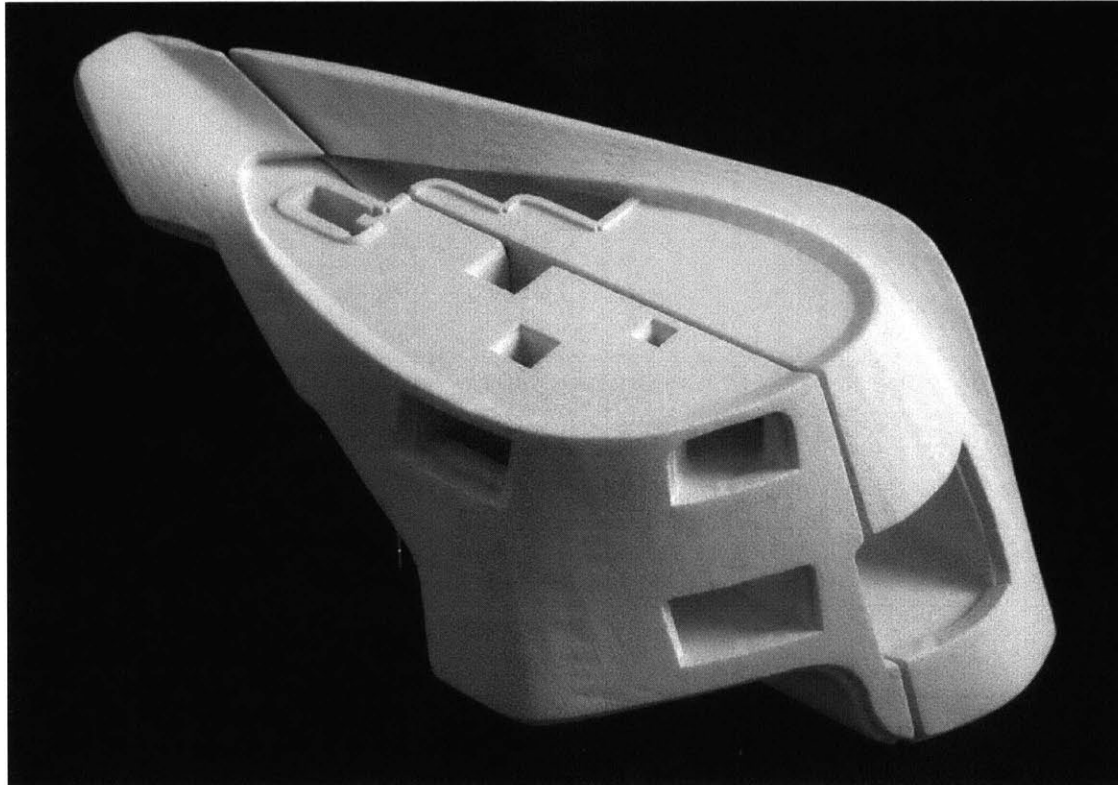


Views of Visitor Center Space

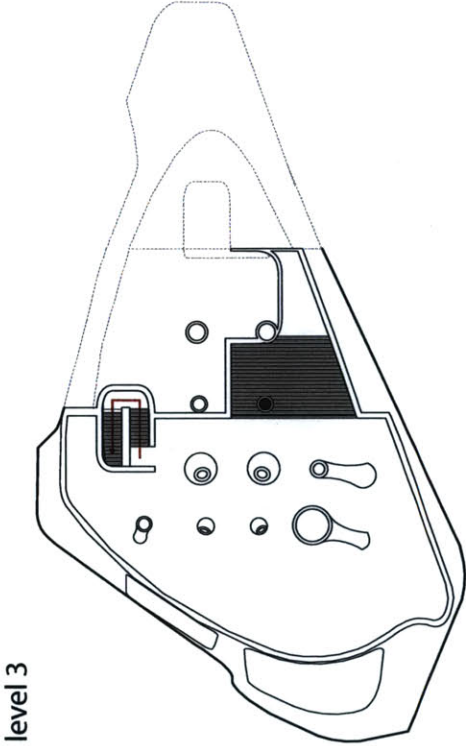
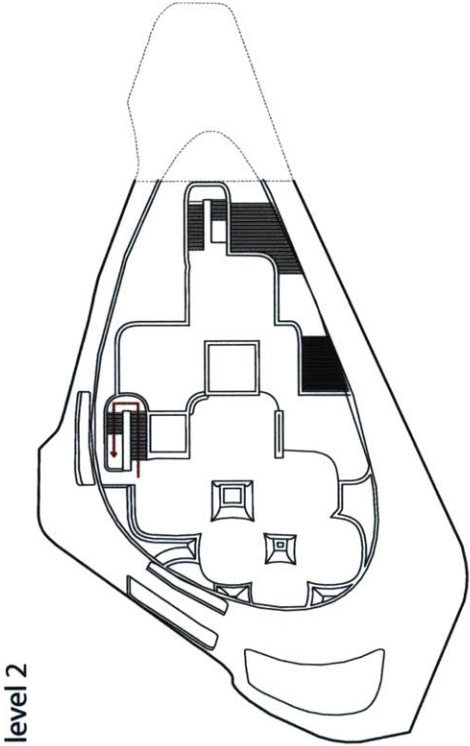
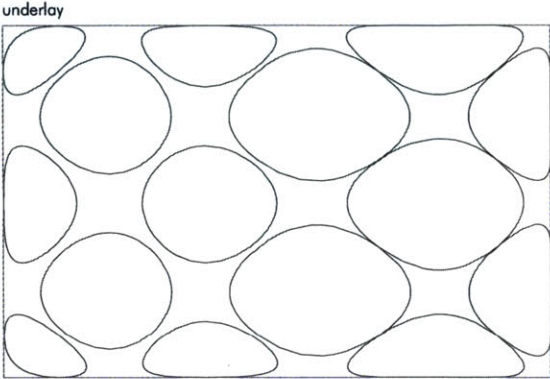
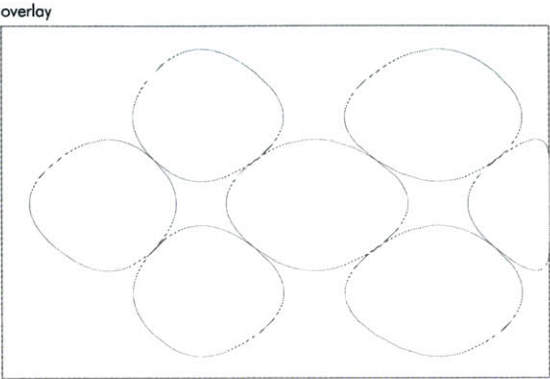




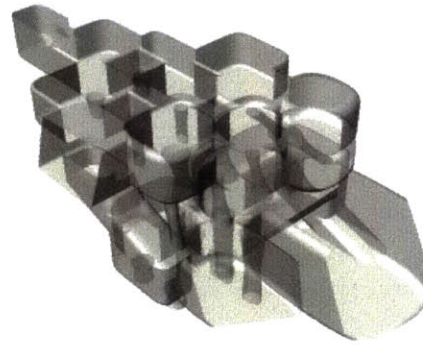
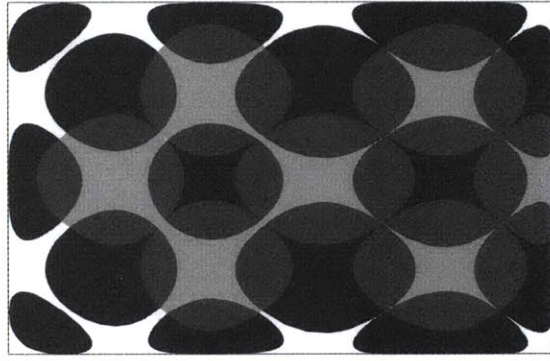
Visitor Center Space
Detail Model



Visitor Center Space Plans

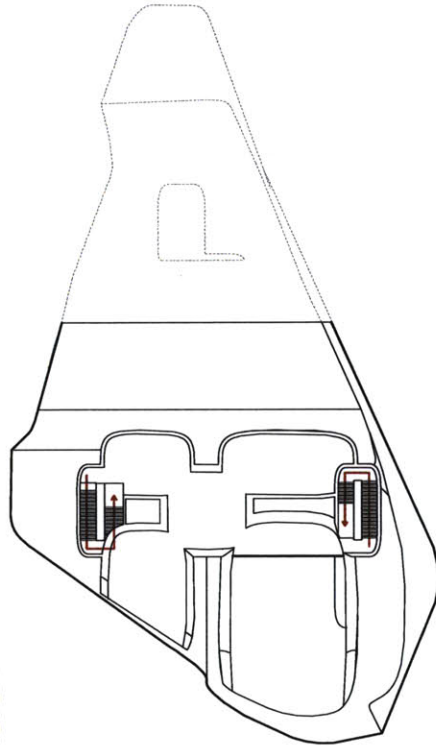


composite

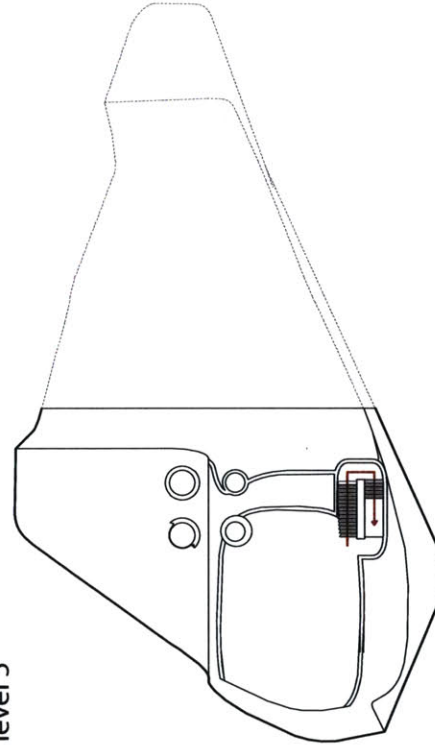


Visitor Center Space Diagram

level 4

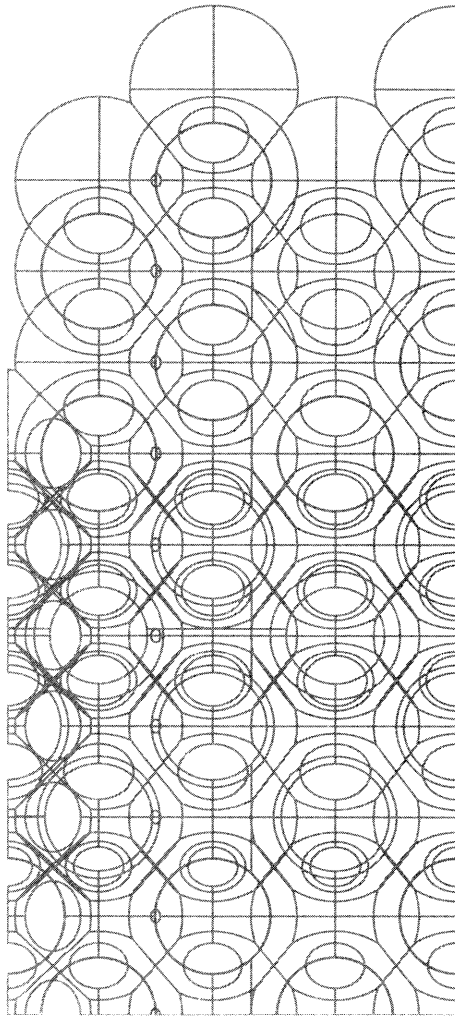


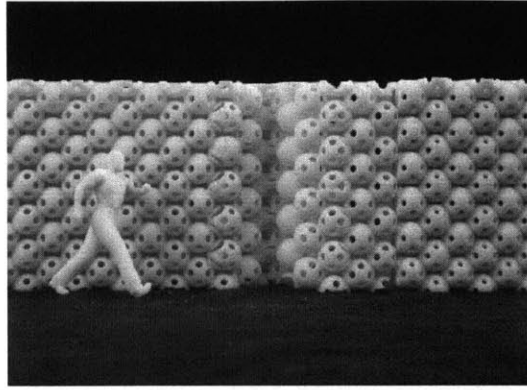
level 5



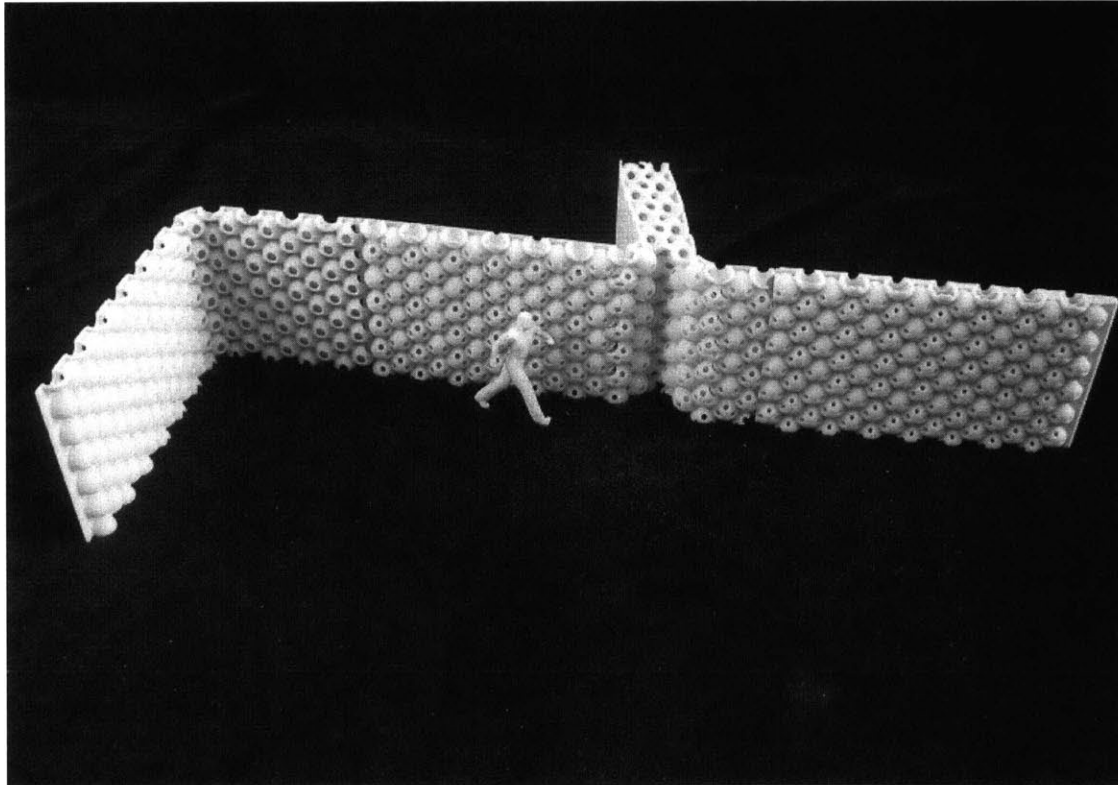
conclusions

The outcome is not meant to suggest a universally applicable material system or production strategy. Rather, it is to develop a way of working, a methodology that can adapt to other situations while still incorporating an underlying philosophy of biologically inspired and parametrically driven design process.

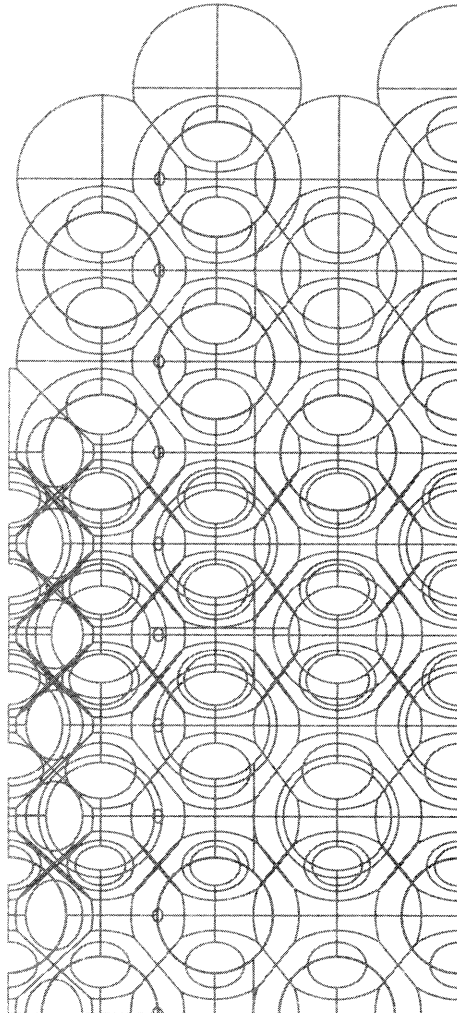




Inhabiting Space Between Wall



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